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Operation and Maintenance of Particulate Control Devices on Selected Steel and Ferroalloy Processes

PEDCo-Environmental, Inc, Cincinnati, Ohio

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OPERATION AND MAINTENANCE OF PARTICULATE CONTROL DEVICES ON SELECTED STEEL AND FERROALLOY PROCESSES



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by

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ABSTRACT

This report deals with the control of fine particulate emission from iron, steel, and ferroalloy plants using electrostatic precipitators (ESP's), wet scrubbers, and fabric filters (baghouses). It provides information on the selection, operation, and expected performance of conventional air pollution control devices, based upon current design practice, theoretical models, performance, cost predictions, and information in the literature.

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METRIC CONVERSION FACTORS

To convert English units	Multiply by	To obtain SI units
British thermal unit (Btu)	1054	Joule (j)
Cubic foot (ft ³)	0.0283	Cubic meter (m ³)
Degrees fahrenheit	5/9 (°F-32)	Degrees Celsius (C)
Foot	0.3048	Meter (m)
Gallon (U.S. Liquid)	0.0038	Cubic meter (m ³)
Gallon (U.S. Liquid)	3.7854	Liter (l)
Horsepower (hp)	746.0	Watt (w)
Inch	0.0254	Meter (m)
Inch	2.54	Centimeter (cm)
Inches of water	248.8	Pascal (pa)
Pound	0.4536	Kilogram (kg)
Ton, short	0.9072	Metric ton (kkg)

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The project director was Mr. Richard W. Gerstle and the project manager was Mr. Michael F. Szabo. PEDCo Environmental, Inc., as the primary contractor and editor, directed and coordinated the entire project effort, as well as provided and integrated into the report, information additional to that provided by the subcontractors.

Cottrell Environmental Sciences researched and coordinated the electrostatic precipitator and wet scrubber information. The scope of work was managed and executed by Mr. David V. Bubenick with the help of Mr. Chin T. Sui and Dr. P. D. Paranjpe. The CES effort was directed by Drs. Paul L. Feldman and Richard S. Atkins.

Midwest Research Institute performed the evaluation in fabric filtration systems. Messrs. Mark Golembiewski, V. Ramana, and Stan Riegel were the principal investigators. The MRI effort was directed by Dr. Krishnan P. Ananth.

1.0 INTRODUCTION

1.1 PURPOSE OF REPORT

This report is intended to provide guidelines by which environmental control personnel and the iron and steel and ferroalloy industries can (1) determine which type of particulate control device is best for a certain process, (2) follow operational and maintenance practices that will maintain high particulate collection efficiencies and minimize malfunctions, and (3) relate the total mass efficiencies of control devices to their efficiencies for collection of particulate in specific size fractions.

1.2 SIGNIFICANCE OF PARTICULATE EMISSIONS

Many undesirable effects have been related to the discharge of particulate matter into the atmosphere. Particulates constitute a health hazard, cause poor visibility, function as a transport vehicle for gaseous pollutants, and (in many cases) are highly active both chemically and catalytically.¹

The full effects of submicron particulates on health are not yet well defined. They are regarded as constituting a whole category of pollutants rather than being a single

pollutant. Once dispersed, they behave (depending on size) similarly to coarse particles and gases. They remain suspended and diffused, are subject to Brownian motion, follow fluid flow around obstacles, and can penetrate deep into the respiratory system.

Particles larger than 5 μm diameter are deposited in the nasal cavity or nasopharynx. Increasing numbers of smaller particles, so minute that they are difficult to measure, reach the lungs. More than 50 percent of particles between 0.01 and 0.1 μm that penetrate the pulmonary compartment are deposited in the lungs. This tendency to penetrate and be captured in the respiratory system is more a function of the geometry of the particles than of their chemical properties.

The unhealthy effects of these captured fine particulates are largely due to their chemical or toxic qualities, although long, fibrous materials exist whose physical qualities may also irritate tissue. Many unknown factors remain, however, so it is unwise to generalize concerning the danger of fine particulates.

1.3 SCOPE OF THE REPORT

This study covers sintering, scarfing, electric arc (EAF), open hearth (OHF) and basic oxygen furnace (BOF) processes in the steel industry; and electric arc furnaces in the ferroalloy industry.

It also deals with the following high-efficiency particulate control devices: dry and wet electrostatic precipitators, wet scrubbers, and fabric filters (baghouses).

Section 2.0 first provides process descriptions and emission characteristics of these processes and the types of conventional control devices used to collect their particulate emissions.

It then discusses control system design parameters, in addition to design philosophy. The major contribution for precipitators and scrubbers in this section, as well as sections 3.0 and 4.0, came from Research-Cottrell supplemented by PEDCo expertise. Some information was obtained from other equipment manufacturers and from the open literature. Both cold-side and wet-type precipitators and venturi-type wet scrubbers are included.

Fabric filter design parameters are based on the literature, site visits, personal communications, and a survey of users by both Midwest Research Institute and PEDCo.

Section 3.0 describes maintenance and operational procedures that contribute to operation of particulate collection devices at maximum efficiency. The discussion encompasses start-up, shutdown, normal operational procedures and common malfunctions.

Fractional collection efficiencies of precipitators, wet scrubbers, and fabric filters are discussed in Section 4.0. Computer models are used to predict the fractional efficiency performance of dry precipitators and venturi scrubbers on appropriate iron and steel and ferroalloy processes. Almost no test data are available for comparison with the models. The fractional efficiency relationships of fabric filters are discussed only briefly because of the lack of a computer prediction model. There are likewise limited fractional efficiency data for fabric filters.

Section 5.0 presents conclusions on the design, operation, maintenance, and the fractional efficiency capabilities of particulate control devices used in iron and steel and ferroalloy processes. A comparison is made of the advantages, disadvantages, and installation and operating costs of each type.

REFERENCES - SECTION 1.0

1. Oglesby, Sabert Jr. Opening Remarks, EPA/Southern Research Institute Symposium on Electrostatic Precipitators for the Control of Fine Particles. EPA-650/2-016, Pensacola Beach, Florida, September 30 - October 2, 1974.

2.0 CONTROL SYSTEMS: PARAMETERS AND CORRELATIONS

2.1 EMISSION SOURCES, CHARACTERISTICS, AND CONTROL SYSTEMS USED

Following is a brief discussion of the processes covered in this report, their particulate emission characteristics, quantities of emissions produced, and the types of conventional control devices used for each process.

2.1.1 Process Descriptions in the Iron and Steel Industry

A flow diagram depicting various processes in a typical integrated iron and steel plant is shown in Figure 2-1. The processes discussed in this report, however, are limited to sintering and scarfing, as well as open hearth, basic oxygen furnace, and electric furnace steelmaking.¹

2.1.1.1 Sintering - Sintering is used to convert iron ore fines and blast furnace flue dust into a product more acceptable for charging the blast furnace.² Materials such as blast furnace flue dust, ore fines, and mill scale are mixed with flux (limestone) and coke breeze and fed to a traveling grate sintering machine. The mixture is heated to a fusion temperature, which causes agglomeration of the iron-bearing particles. Combustion is initiated on the surface of the mixture in the ignition furnace, which is

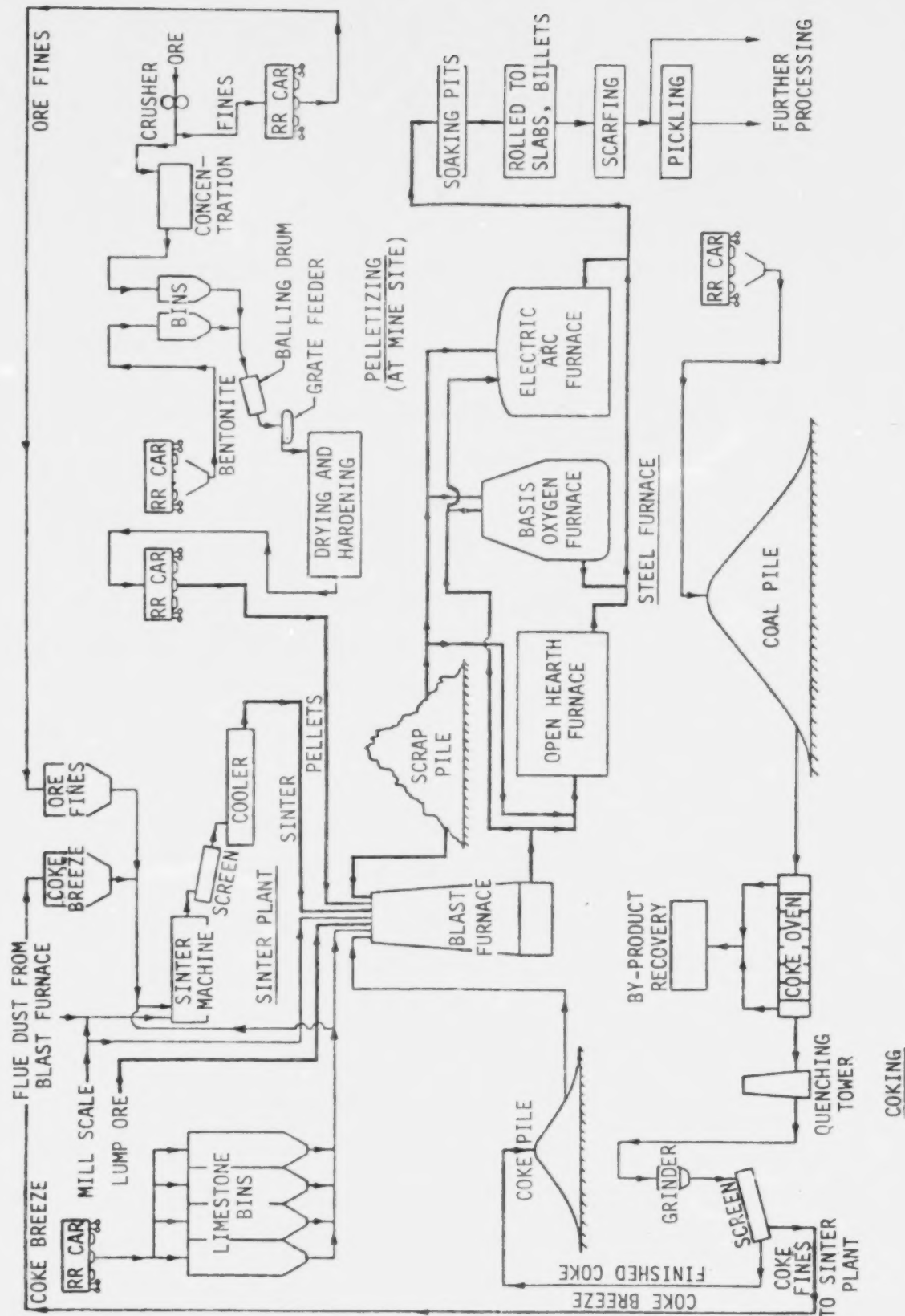


Figure 2-1. A composite flow diagram for a steel plant.

either gas- or oil-fired. Once the coke breeze is ignited, combustion is maintained by a downdraft of air through the flat, porous bed of mixture. To provide for a reasonably uniform distribution of combustion air, the section under the bed is separated into compartments known as wind boxes.³ Modern sintering plants have capacities ranging from 2000 to more than 6000 tons/day with exhaust fans drawing air through the bed of the largest strands at a rate of more than 500,000 acfm measured at a temperature of 350°F.²

At the discharge end of the sintering machine, the incandescent sintered material is dumped from the grate into a crushing and screening section where large pieces are broken up. Directly below the breaker are screens to remove fines for recycling to the sinter plant. The crushed pieces are conveyed to the sinter cooler. In some of the newer plants, discharged material may first enter the sinter cooler and then be conveyed to a different location for crushing and screening.

Sintering machines process a wide variety of feed materials and produce a considerable amount of emissions. The quantity and nature of the emissions vary from plant to plant.

Small amounts of dust are created in the handling and grinding of raw materials. Emissions also include dust

which has been sucked through the grate bars into the wind box, combustion gases from ignition and firing, and dust generated in the screening and cooling operations.

2.1.1.2 Open Hearth Furnace (OHF) Steelmaking - At one time about 90 percent of the steel made in the United States came from open hearth furnaces. Recently, increased use of the basic oxygen furnace and electric furnace has reduced open hearth production.⁴

In the open hearth process, steel is usually made from a mixture of scrap and hot metal in varying proportions. Impurities such as carbon, manganese, silicon, sulfur, and phosphorus are reduced to specified levels by oxidation. The refining operation is carried out by means of a slag that forms a continuous layer on the surface of the liquid metal. This slag is composed essentially of lime combined with the oxides of silicon, phosphorus, manganese, and iron, all of which are formed or added during the operation.²

The furnace consists of a shallow, rectangular basin enclosed by walls and a roof of refractory brick.⁴ Heat is supplied from burners at one end. The fuel used includes coke oven or natural gas, oil, tar, or pitch. The flame from combustion of the fuel travels the length of the furnace above the charge which rests on the hearth. On leaving the furnace, the hot gases are conducted in a flue down to

regenerative chambers commonly called "checkers" or "checkerwork." This mass of refractory brick is systematically laid to provide a large number of passageways for the hot gases. It absorbs heat and reduces gas temperature from approximately 3000°F to between 1200 and 1500°F.^{2,3} All the elements of the combustion system (burners, checkerwork, and flues) are duplicated at each end of the furnace. After a timed interval, the flow of flame and flue gases is reversed so that the heat stored in the checkers is given up to a reverse-direction stream of air flowing to the burners.² From the checkers, the gases are normally directed to a waste heat boiler, where the temperature is further lowered to an average of 500 to 600°F.² Open hearth furnace capacities vary from as little as 30 tons to as much as 500 tons/heat (i.e., batch of finished steel).³ The median is between 100 and 200 tons/heat. The time required to produce a heat is commonly between 8 and 12 h when normal amounts of oxygen are used.²

In recent years with the practice of using high oxygen flow rates (oxygen lances) from hot metal addition to tap, production rates of 90 to 100 tons/h are conceivable in a 300-ton furnace. Oxygen consumption under these conditions ranges from 600 to 1000 cu ft/ton (900 to 1667 scfm during the period in which oxygen is added).²

2.1.1.3 Basic Oxygen Furnace (BOF) Steelmaking - The basic oxygen furnace is a relatively new development in the steel industry. The first of its kind in the United States was installed in 1955.³ The furnace is a pear-shaped structure with a refractory lining. A water-cooled lance is used to supply pure oxygen (typical ratio of 2000 ft³/ton steel produced) to a mixture of steel scrap, hot metal, and flux materials. Furnace capacities range from 75 to 325 tons/heat and the time required per cycle is very short. A typical 150-ton BOF operation has the following heat time:⁴

Charge scrap	1 min
Charge hot metal	2 min
Oxygen blow	20 min*
Chemical tests	5 min
Tapping time	<u>5 min</u>
Total time	33 min

The BOF process differs from open hearth practice in that external heat need not be supplied to facilitate the refining of the iron. The sources of heat are (1) sensible heat from the hot metal, and (2) heat released by the exothermic reactions between oxygen and metalloids in the charge (primarily silicon and carbon).⁴ The BOF has displaced the open hearth as the major steel production process, but is much less flexible because of the limited amount of scrap (25 to 30 percent) that can be used in the

* Reblow and second analysis is also common because of missed specifications.

charge. Its capacity in an integrated steel plant, therefore, is closely associated with the availability of hot metals.

2.1.1.4 Electric Arc Furnace (EAF) Steelmaking - In the electric furnace process, steel scrap and flux materials are charged into a cylindrical vessel with a refractory lining and three large carbon electrodes protrude through the furnace roof. Heat required for the metallurgical reaction is generated by the arc from the three electrodes using currents ranging from 10,000 to 20,000 amps.² Furnace capacities vary widely, but generally range from 50 to 200 tons/heat. Heat times vary up to approximately 4 h.

The electric furnace process cycle closely approximates that of the open hearth, except for the fact that a shorter overall time is needed. The cycle consists of charging, meltdown, the molten metal period, boil, the reducing or refining period, and the pour (tap).² A series of charges is required in this process owing to the low bulk density of scrap. As a rule, no hot metal is used.^{3,4} An exception is Armco Steel in Houston, Texas.

Because of the limits the BOF process puts on the use of scrap, the electric furnace has gained increasing importance. It permits a high degree of operational control and is generally preferred for the manufacture of alloy and

stainless steels.⁴ Variations of electric furnace operations include use of oxygen lancing, oxygen fuel gas burners and preheated scrap. The use of oxygen fuel during the meltdown period has been reported to increase production from 15 to 20 percent and to decrease power consumption by 15 to 20 percent.²

2.1.1.5 Scarfig - Scarfig is a conditioning process for removing surface defects from blooms, billets, and slabs prior to their being rolled into semifinished steel products. The operation is usually done after the slab, bloom, or billet has been heated to the rolling temperature, but it may also be performed on cold steel.⁵ The process consists essentially of burning the surface of the steel with a jet of oxygen in combination with a fuel gas, such as acetylene or natural gas. The purpose of the fuel gas is to ensure that the steel is heated to a sufficiently high surface temperature (about 1600°F) to bring about rapid oxidation and localized melting of a thin layer of metal.^{2,5} Originally the process was a manual one. In recent years the so called hot scarfig machine has come into wide use. Approximately 1/8 in. of metal is removed from all four sides of the red-hot billets, blooms, or slabs as they travel through the machine in a manner similar to the journey through rolling mills.²

2.1.2 Emission Characteristics - Iron and Steel

Emission characteristics for the various sources discussed in this section are summarized in Table 2-1. Estimations of volume flow rate, emission rates, and particle size distribution vary for the same process depending upon the source. Particle size distributions from most literature sources do not list the percentage of particles in the smaller size ranges ($< 2 \mu\text{m}$). Therefore, when estimating particle concentrations as a function of particle size and predicting fractional efficiencies later in the report, estimates by Weast et al.⁶ are used. Discussions on emissions (uncontrolled) from each process follow.

2.1.2.1 Sintering - The concentration of particulates in the wind box under the grate during ignition appears to be about 0.5 to 3 gr/scf.⁴ This effluent has a temperature of about 160 to 390°F.² Based on an average volumetric flow rate of 60 scfm/tons/day capacity³ and plant capacities of 2000 to 6000 tons/day,² an exhaust gas would have flow rates of 120,000 to 360,000 scfm. A typical particle size distribution in the windbox gases (given in Reference 7) is as follows:

15 to 45%	$< 40 \mu\text{m}$
9 to 30%	$< 20 \mu\text{m}$
4 to 19%	$< 10 \mu\text{m}$
1 to 10%	$< 5 \mu\text{m}$

Table 2-1. SUMMARY OF EMISSION CHARACTERISTICS FROM

VARIOUS LITERATURE SOURCES

Emission source	Gas temperature, °F	Volume flow rate, scfm	Uncontrolled particulate emission, gr/scf	Particle Size Distribution	
				General	Specific ^f
<u>Sintering</u>					
Combustion waste gas (wind box)	160-390 ²	120,000-360,000 ^a	0.5-3.0 ⁴	15-45% < 40 µm ⁷ 9-30% < 20 µm 4-19% < 10 µm 1-10% < 5 µm	$\bar{x} = 70, \sigma = 6.67$ w/o mechanical collector $\bar{x} = 7.7, \sigma = 3.50$ w mechanical collector
Discharge end	170 ^b	100,000-300,000 ^c	3-8 ³	50% > 100 µm ⁷ 40% 10-100 µm 10% < 10 µm	-
<u>Scarfing</u>	100 ^b	20,000-150,000 ⁷	0.4-0.8 ⁷		no data available
<u>Open hearth furnace</u>	500 ^d -1500 ^{2,3}	25,000-200,000 ⁷	0.4-0.6 ²	69-92% < 10 µm ⁷ 45-75% < 5 µm 20-45% < 2 µm	$\bar{x} = 0.21, \sigma = 2.86$
<u>Basic oxygen furnace</u>					
Waste gas	560 ^d -3000 ⁷	35,000-250,000 ⁷	2-10 ⁷	85-95% < 1 µm ⁷	$\bar{x} = 0.27, \sigma = 1.82$
Hot metal reladling	220 - 260 ⁹	100,000 ³	0.4-0.5 ³	67% < 149 µm ⁹ 46% < 74 µm 16% < 10 µm 3% < 1 µm	-
<u>Ferroalloy furnace</u>	215-3000	100,000-400,000 ¹⁷ (open) 1000-7000 ¹⁷ (semi-enclosed and sealed)	0.2-2.7 ⁷ (open) 5-30 ⁵ (closed)		$\bar{x} = 0.19, \sigma = 3.00$ (ferrosilicon alloys) $\bar{x} = 0.78, \sigma = 2.12$ (ferromanganese alloys) $\bar{x} = 0.86, \sigma = 4.19$ (ferrochromium alloys) $\bar{x} = 0.50, \sigma = 3.36$ (miscellaneous alloys)
Steel electric furnace ^e	215-3000 ⁷	10,000-100,000 ⁷	0.1-10 ⁷	60% < 5 µm ⁷	$\bar{x} = 0.80, \sigma = 9.30$

^a Based on an average flow rate of 60 scfm/ton/day capacity and plant capacities of 2000-6000 tons/day.³^b Estimated by EPA personnel.⁸^c Based on a flow rate of 50 scfm/ton/day capacity and plant capacities of 2000-6000 tons/day.³^d With waste heat boiler.^e Both oxygen lanced and nonoxygen lanced operations are included in the reported values.^f From Weast et al.²³

The chemical composition of a wind box dust is shown in Table 2-2.

Table 2-2. CHEMICAL COMPOSITION OF SINTER STRAND
WIND BOX DUST¹⁰

Compound	Wt %
Fe ₂ O ₃	45-50
SiO ₂	3-15
CaO	7-25
MgO	1-10
Al ₂ O ₃	2-8
C	0.5-5
S	0-2.5
Alkali	0-2

A second and the major emission point from the sintering process is the discharge end of the sintering machine. A gas flow rate of 50 scfm/tons/day capacity is usually required for ventilation, although one plant reportedly has gas cleaning equipment with a rate of 100 scfm/tons/day of sinter capacity.³ Dust concentrations as high as 4 to 6 gr/scf have been measured in Britain, and one U.S. plant reports 3 to 8 gr/scf in 100,000 scfm of ventilation air.³ Particle size data from Reference 7 are as follows:

50% > 100 μm
40% 10-100 μm
10% < 10 μm

Other major pollutants from sintering plants are SO_x and CO. Gaseous and particulate fluorides are also emitted from a few western sintering plants processing ore with a high fluoride content.²

2.1.2.2 Open Hearth Furnace (OHF) - Particulate emissions, gas volumes, and gas compositions of open hearth furnaces vary rather widely over a single heat.³ Factors which affect emission rate include quantity and cleanliness of the scrap iron charged. Oxygen lancing generates considerably more particulate matter. The average emission rate appears to be about 0.4 gr/scf for the conventional furnace and 0.6 gr for the oxygen-lanced furnace.²

Usually up to 90 percent of particulates from open hearth furnaces are iron oxides, predominantly Fe_2O_3 . During the lime boil period (approximately 38% of total heat), however, the percentage of iron oxide may be less. When large amounts of scrap are used in the charge, zinc oxides may predominate during part of the heat.² Particle size distribution varies considerably during the heat. Over the entire heat of a furnace that is not oxygen-lanced, about 50 percent are less than 5 μm . For an oxygen-lanced furnace, Reference 7 lists the following size distributions:

<u>During lime boil</u>	<u>Composite</u>
92% < 10 μm	69% < 10 μm
75% < 5 μm	45% < 5 μm
45% < 2 μm	20% < 2 μm

Weast et al.⁶ indicate a much smaller particle size distribution than the above data (see Table 2-1).

Other pollutants in the flue gas contain SO_x , NO_x , and fluorides. Emissions of CO, however, are considered negligible.³

2.1.2.3 Basic Oxygen Furnace (BOF) - Particulate emissions from BOF range from 2 to 10 gr/scf.⁷ The effluent gas may have a temperature of 560 to 3000°F depending on utilization of a waste heat boiler and a flow rate of 35,000 to 250,000 scfm.⁷ About 85 to 95 percent of these particulates are less than 1 μm in size.⁷

Waste gases from the BOF contain large amounts of CO, which are normally burned in the hood. According to Reference 3, there is one installation in the United States where the gases are cleaned prior to combustion of the CO.

Transfer of hot metal to the BOF creates additional particulate emission problems. During the transfer, known as reladling, significant quantities of kish (precipitated graphite flakes) and iron oxide particulates are generated. Dust loadings of 0.4 to 0.5 gr/scf in an air volume of 100,000 scfm are reported.³ The gas stream temperature is

reported to range from 220 to 260°F.⁹ The following particle size distribution is reported in reference 9:

33%	<	149	μm
54%	<	74	μm
84%	<	10	μm
97%	<	1	μm

2.1.2.4 Electric Arc Furnace (EAF) - During the melt cycle, both particulate matter and carbon monoxide are produced. The rate of particulate emissions varies considerably in a given cycle. Information from six steel plants indicates a range of uncontrolled emissions of 23 to 58 lb/ton of carbon steel produced.³

Most emissions occur during the early "melting" portion, although significant quantities are also emitted during charging, back charging, tapping, and oxygen-blowing operations. Information supplied by steel manufacturers on the quantity of particulate matter collected by control devices suggests that 30 lb of dust are emitted per ton of steel when melting carbon steel and 15 lb of dust per ton for alloy steel.

Particulate emissions may also vary from cycle to cycle because of several factors:

1. Contamination of the scrap steel with dust, oil, or volatile metals will increase emissions during charging.
2. An increase in electrical power to a furnace will increase emissions during the scrap melting.

3. An increase in the quantity of oxygen blown will increase emissions during the blow.

Carbon monoxide is generated by reaction of the carbon electrodes (or carbon in the steel) with oxygen. Much of the carbon monoxide is oxidized to carbon dioxide as it leaves the furnace in the fume exhaust system. These carbon monoxide emissions can be as high as 6 lb/ton of steel produced,³ although they vary considerably during a furnace cycle. Peaks are observed during scrap melting when maximum electrical power is on and also during oxygen blows.

Tables 2-3 and 2-4 give the particle size distribution and composition of electric arc furnace fumes, as reported in Reference 11. Reference 7 gives a particle size distribution of 60 percent $< 5 \mu\text{m}$ for electric arc furnaces. The particle size distributions presented by Weast et al.⁶ indicate a much higher incidence of fine particles than do references 7 or 11.

The gas volume required for proper ventilation of electric arc furnaces depends on:

1. Melting rate and electrical energy input per ton of metal charged.
2. Oxygen lance rate.
3. Scrap charge composition (especially oil content).
4. Type of hooding employed (discussed later).

Table 2-3. ELECTRIC ARC FURNACE FUME
PARTICLE SIZE DISTRIBUTION¹¹

Particle size (μm)	Wt % in size range
0-2	10
2-4	17
4-8	34
8-12	9
12-44	15
>44	15
Total	100

Table 2-4. TYPICAL CHEMICAL ANALYSIS OF
ELECTRIC ARC FURNACE FUME¹¹

Compound	Wt %
Total iron	32.2
Loss on ignition	10.1
CaO	18.6
SiO ₂	10.8
Total carbon	8.3
MgO	7.1
Al ₂ O ₃	5.7
Cr ₂ O ₃	1.3
MnO	1.2
ZnO	1.03
V ₂ O ₅	<1.
Total S	0.60
Na ₂ O	0.59
TiO ₂	<0.50
F	0.49
K ₂ O	0.37
BaO	<0.20
Pb	0.15

2.1.2.5 Scarfig - Information on pollutants generated in the scarfig process is very meager. Reference 7 gives a range of particulate grain loadings from 0.4 to 0.8 gr/scf. Gas volumes are reported to range from 20,000 to 150,000 scfm.⁷

2.1.3 Control Methods - Iron and Steel

Particulate control equipment used in the various processes is discussed in the following section. The information presented here is primarily from Reference 3.

2.1.3.1 Sintering - Dry and wet electrostatic precipitators, scrubbers, and cyclones are the principal means for controlling emissions from the wind boxes of sinter machines. However, due to large variations in the materials being processed, no single control device can be generally applied.³ One problem, as far as electrostatic precipitators are concerned, is that their performance is affected by oil in the recycled fines and by increased limestone additions in the charge.^{3,12}

Various types of pilot-scale scrubbers have been tested by Kaiser Steel Company at Fontana, California. They typically showed erratic efficiencies, sludge buildup, scaling, and high energy requirements.¹³ One steel company reportedly tested a pilot-scale scrubber and found a problem with unburned carbon.³

Armco Steel Company pilot-tested both high energy venturi scrubbers and the Lone Star Steel Steam Hydro Scrubber on their Houston Sinter Plant wind box emissions.¹⁴ Both were found to satisfactorily remove particulate and, to a lesser extent, hydrocarbons, although the steam hydro gave more efficient removal of hydrocarbons. Thus, because the hydrocarbons were a primary contributing factor to stack opacity, the high hydrocarbon efficiency gave an edge to the steam hydro system, which also had a slight economic advantage, but only due to the availability of steam generating capacity and low cost fuel to generate the steam. The steam hydro was installed in 1975 as six parallel units, five operating, and one spare. The greatest problems have been with corrosion of carbon steel components of the water treatment system because of poor pH control.

Bethlehem Steel Corporation has tested a full scale wet ESP demonstration system for wind box emission control at their Lackawanna, New York, plant.¹⁵ They found that the wet ESP operated satisfactorily during the 3-month test period, with outlet loading lower than applicable regulations. However opacity was not reduced sufficiently to meet visible emission regulations.

Kaiser Steel Company³ uses a baghouse for particulate control of wind box gases. The company decided that this

method suited them best following 11 years of pilot plant studies. The Weirton Steel Company pilot-tested a baghouse, but found that oil fumes were not condensed at the operating temperature of the baghouse and left a visible plume. They also found that the dust was pyrophoric.³ Inland Steel installed a baghouse on the wind box of their sinter machine down-stream of a cyclone and precipitator in October 1975. They have had numerous operating problems, the main one being bag replacement. Problems with bag cleaning systems and anti-collapse rings have been partially responsible for the high number of bag replacements.

Republic Steel at Gadsden, Alabama, is operating pulse-jet baghouses on both wind box and discharge ends. There were initial problems with high pressure drop through the wind box bags which now seem to be solved. Wind box A/C Ratio is 6:1 with dacron felt bags. Discharge end A/C ratio is 7.4:1 with Nomex felt bags.

Both baghouses and medium energy wet scrubbers have been used on the discharge end of sinter plants. It appears that either technique reduces plume appearance to invisibility, or nearly so. The major equipment problems appear to be abrasion and, in the case of wet systems, a buildup of lime scale.³

Because the gas temperatures involved a range from 300 to 400°F, the actual bags used in all these cases were made

of glass fabric. It is also reported that the large size of baghouses discourages their use in many plants. A list of U.S. integrated iron and steel plants and the type of equipment used to control emissions from the wind box and from the discharge end of the sinter plant is shown in Appendix A-1.

2.1.3.2 Open Hearth Furnace - The majority of open hearth furnaces are equipped with electrostatic precipitators. Wet scrubbers have been used in some cases, when the shop either had no waste heat boilers or when existing boilers could not lower gas temperatures enough to warrant installation of electrostatic precipitators or baghouses.⁴

Two cases have been reported in the United States where baghouses have been used for open hearth furnace gas cleaning.³ The Bethlehem Steel Corporation's Sparrows Point plant operated a baghouse on a single open hearth furnace for about 2 years. The baghouse was selected for this unique application because it was considered best able to handle fluctuations in gas volume, gas composition, and dust concentration from a single furnace. This particular furnace was shut down when a basic oxygen furnace shop was built. Performance of the baghouse from the standpoint of gas cleaning was reportedly excellent. Outlet dust concentration was 0.007 gr/scf, but the stack was never clear

because of leakage at a damper valve. The cost of this installation was over three-quarters of a million dollars.³

The only other application of a baghouse to an open hearth furnace is by the Ohio Steel Foundry, which uses small (30 to 40 tons) open hearth furnaces at its plant. These baghouses have been operating, apparently satisfactorily, for 3 to 4 years.³

A list of U.S. open hearth installations and the associated particulate control device is presented in Appendix A-2.

2.1.3.3 Basic Oxygen Furnace - The two gas cleaning systems applied to BOF's in the United States are high energy venturi scrubbers and electrostatic precipitators. They are used in approximately equal numbers. There is one reference to the application of a baghouse to a BOF in Europe, but it does not seem to be an attractive system.³ However, in the United States, Crucible Steel at Midland, Pennsylvania, is retrofitting a fabric filter to their BOF shop.

Two different hood systems are used to capture emissions from BOF's. One system uses an open (or combustion) hood, which has a 1.5 to 2 ft clearance above the furnace rim. The other system uses a retractable closed hood, which fits rather closely around the top of the furnace and minimizes air from being drawn into the exhaust system.¹⁴

The closed hood was designed to minimize exhaust volume and to reclaim carbon monoxide. In many countries this carbon monoxide is collected for use as a fuel or as a feed gas for petrochemical processing operations. In the two U.S. plants using closed hoods, however, exhaust gases are currently flared and there is no heat recovery. The volumetric flow rate through the closed hood system is generally less than 20 percent of the flow rate in an open hood system. However, the high concentrations of combustible carbon monoxide limit the choice of cleaning equipment to a single type, the high energy venturi scrubber.¹⁶

The particulate emissions from hot metal reladling are a mixture of kish and submicron iron oxide fume. Cyclones and baghouses are the only control equipment installations to be applied on a large scale.³

Appendix A-3 provides a list of U.S. BOF installations and their associated particulate control devices.

2.1.3.4 Electric Arc Furnace - Fabric filters (baghouses) are the most commonly used devices for cleaning electric furnace gases, although venturi scrubbers and electrostatic precipitators are also occasionally installed.¹⁷ When the fume-capturing systems involve large volumes of ventilation air, however, operating costs generally limit the control device to fabric filters.¹⁷

The capture systems normally used are: (1) direct shell evacuation in combination with natural ventilation through the open roof, (2) building evacuation in a shop with a sealed roof, (3) canopy hoods in a shop with a sealed roof, (4) canopy hoods in combination with natural ventilation through the open roof, and (5) combinations of direct shell evacuation with systems (2), (3), or (4).¹⁷

The direct shell evacuation system, which withdraws emissions directly from within the furnace before they escape and are diluted by ventilation air, has the lowest gas volume. When a fabric filter is used, however, the hot furnace gas must first be cooled by water sprays, radiant coolers, dilution air, or some combination of these to prevent degradation of the fabric.¹⁷

A listing of electric arc furnaces in the United States and associated control devices where known, are presented in Appendix A-4.

2.1.3.5 Scarfig - Scrubbers, cyclones, baghouses, water flumes with water sprays, and wet and dry ESP's are used to control emissions from scarfig installations in the United States. Wet ESP's have been used more than dry ESP's. Bethlehem Steel recently pilot-tested two wet ESP's at its Lackawanna, New York, 44-inch rolling mill with excellent results¹⁵ (outlet dry particulate loadings of less than 0.01

gr/scfd for all but one test). The only application of a fabric filter to control particulate emissions from scarfing operations in the integrated iron and steel industry is at Bethlehem Steel Corporation's Los Angeles plant. Scarfing emissions in this case are exhausted to a baghouse, which is also used to control emissions from the electric furnace.^{5,18}

2.1.4 Process Description - Ferroalloy Furnaces

A ferroalloy is an alloy of iron with one or more other metallic elements used for deoxidizing molten steels and making alloy steels. Ferroalloys are produced predominantly in electric arc furnaces, so only this type of furnace will be discussed.¹⁹ Emissions from such furnaces and the control devices used will also be described.

A typical flow diagram of ferroalloy production is shown in Figure 2-2.¹⁹ The furnace itself consists of a hearth lined with a high temperature refractory which has holes to permit tapping of metal and slag. The furnace shell and its hood or cover components are made of steel and are water-cooled. Above the hearth are three electrodes which extend 3 to 5 ft into the charge materials. The charge (i.e., raw ore, coke, and limestone or dolomite) melts as the electrical energy is converted to heat. Chemical reactions between the coke and oxygen in the metal oxides form carbon monoxide and reduce the ores to base metal.¹⁹

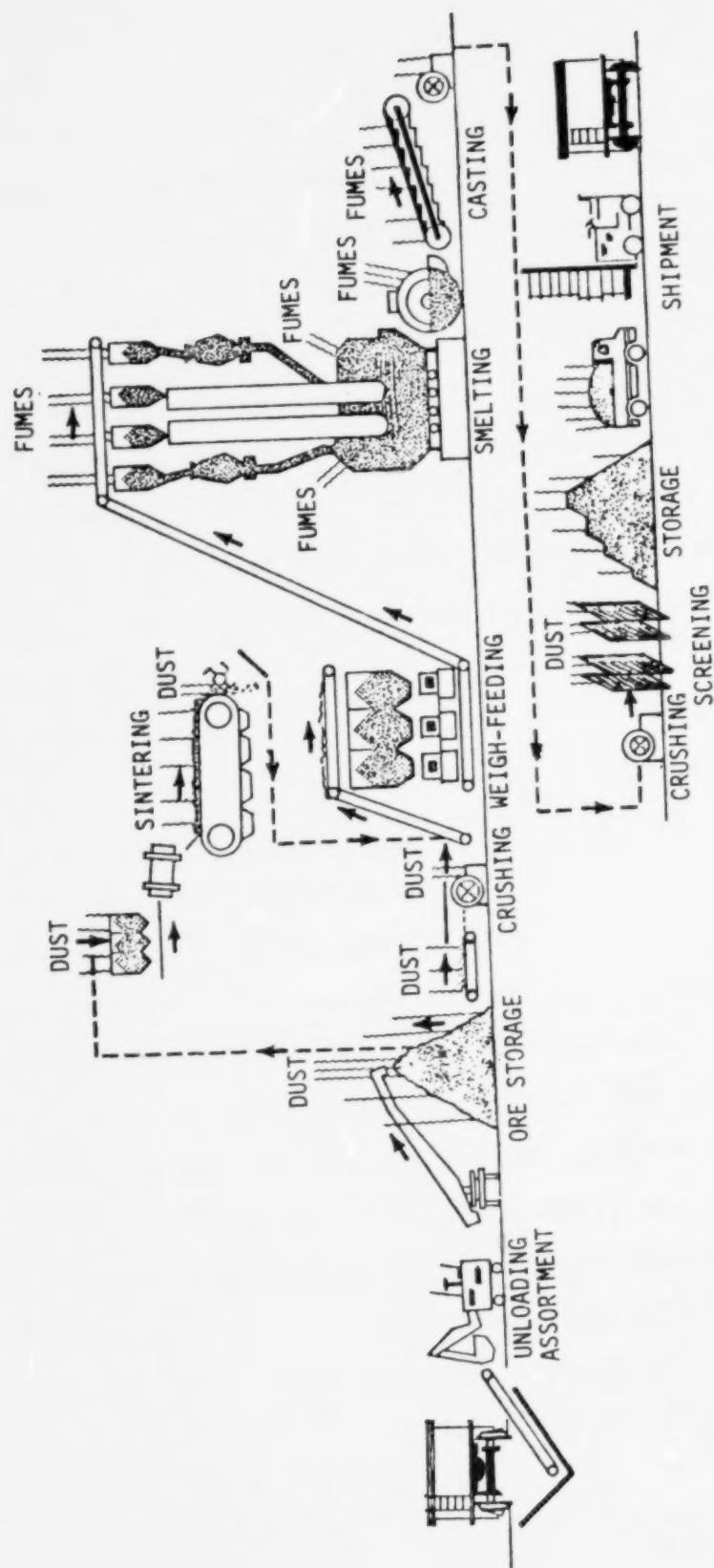


Figure 2-2. Ferroalloy production process.

The furnace design may be open, semienclosed, or sealed. Diagrams of the three types of furnace are shown in Figures 2-3 through 2-5.¹⁹ Both the semienclosed and sealed furnaces are less flexible than the open furnace. A specific sealed furnace can be used to produce only one family of ferroalloys. It cannot be adapted to the production of others without changing the electrode spacing (which is determined by the product family). In addition, the furnace cover must also be replaced. Thus, modification of sealed furnaces to produce other products is prohibitively expensive. Product flexibility is possible at minimum cost with those open furnaces which have multiple transformer taps and adjustable electrodes.¹⁹

2.1.5 Emission Characteristics - Ferroalloy Furnaces

The major pollutants from electric furnaces are particulates and carbon monoxide. Carbon monoxide is formed as a by-product of the electric arc furnace reduction process. Depending on the type of furnace, this gas is either burned at the surface of the charge material or cleaned by an emission control system. After cleaning, it may be flared or used for fuel for other chemical processes.¹⁹

Particulate emissions from the furnace vary with:¹⁹

- ° The type of alloy produced;
- ° Choice and size of raw materials;

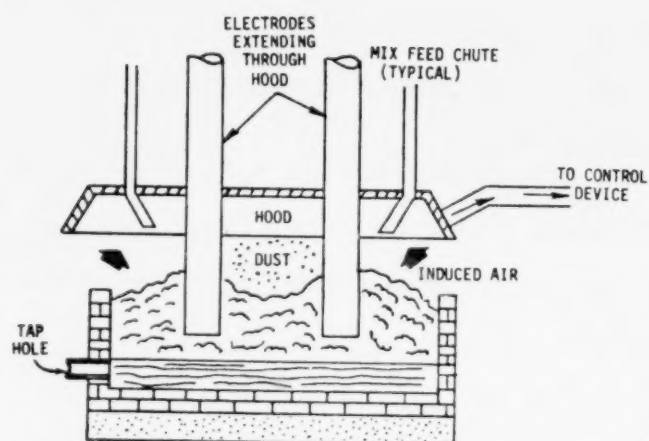


Figure 2-3. Open furnace.

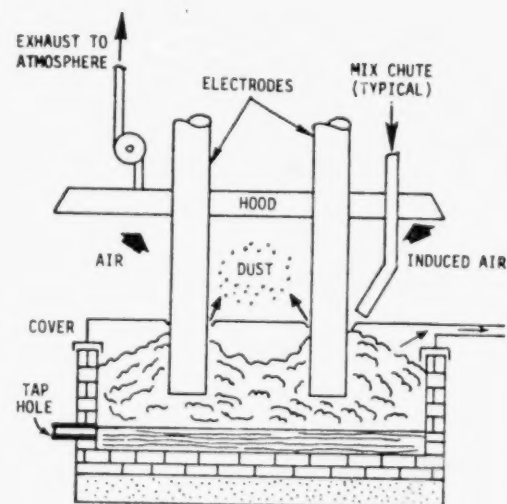


Figure 2-4. Semienclosed furnace.

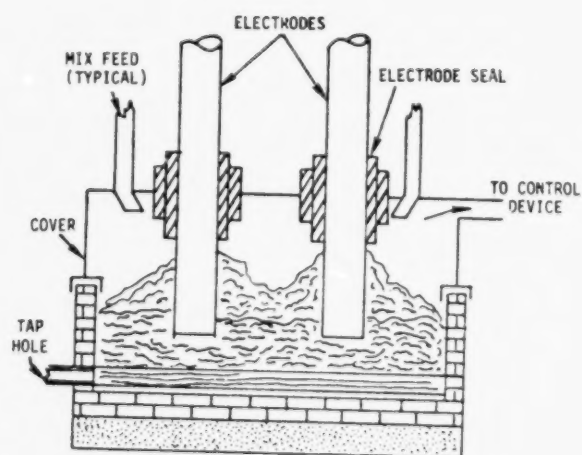


Figure 2-5. Sealed furnace.

- ° Choice of size of raw materials;
- ° Operating techniques; and
- ° Existence of a furnace shutdown or start-up condition.

Uncontrolled grain loadings range from 0.2 to 2.7 gr/scf for ferrosilicon production in open furnaces.⁷ Semienclosed and sealed furnaces have lower flow rates and thus would have higher particulate concentrations (5-30 gr/scf for closed furnace).¹⁷ Table 2-5 lists properties of particulate emissions from ferroalloy furnaces, as reported in Reference 18.

Gas volumes from open furnaces range from 100,000 to 400,000 scfm.¹⁹ Based on EPA test data, semienclosed and sealed furnaces have volumetric flow rates of about 1000 to 7000 scfm.¹⁹

Carbon monoxide is the major by-product of ferroalloy production. In fact, the weight of CO emitted from the melt can exceed that of alloy produced.¹⁷ Other components of the gaseous discharge include hydrogen and volatile hydrocarbon. The latter comes from the electrodes and from oil on the surface of the steel shavings.

Operation of ferroalloy furnaces produces particulate emissions at three principal points:

1. The top of the furnace, transported reaction gases.

Table 2-5. PROPERTIES OF PARTICULATE EMISSIONS FROM FERROALLOY FURNACES^a

Parameter	Alloy type	50% Fe Si	SI Mn	Fe Mn	H.C. Fe Cr
Furnace hood type		Open	Covered	Open	Covered
Particle size, μm					
Maximum		0.75	0.75	0.75	1.0
Range of most particles		0.05-0.3	0.2-0.4	0.05-0.4	0.1-0.4
Chemical analysis, wt % ^b					
SiO ₂		68-88	15.63	25.48	20.96
FeO			6.75	5.96	10.92
MgO			1.12	1.03	15.41
CaO				2.24	
MnO			31.35	33.60	2.84
Al ₂ O ₃			5.55		7.12
Cr ₂ O ₃					29.27
Loss on ignition			23.25	8.38	

^a"Air Pollution Control Technology and Costs: Seven Selected Emission Sources". Prepared by Industrial Gas Cleaning Institute; EPA-450/3-74-060.

^bStandard metal oxides analysis-compounds not necessarily found in the chemical forms listed.

2. The furnace tapholes. Since most furnaces are tapped cyclically rather than continuously, the source is active only about 15 percent of the time.
3. The ladle after tapping, which is also a non-continuous source of particulates.

The mass median diameter of emissions from open furnaces producing ferrochrome silicon, silicomanganese, and high carbon ferrochrome has been measured by EPA to be between 0.66 and 1.7 μm . This range is in good agreement with the data presented by Weast et al.,⁶ except for the ferrosilicon alloy, which Weast reports as being lower than 0.66 μm , mass median diameter.

Particles of this size are difficult to collect and usually require high expenditures of energy. Agglomeration of the particles, however, can make the effective particle size to the collector much larger than that indicated in Table 2-5.

2.1.6 Control Methods - Ferroalloy Furnaces

2.1.6.1 Open Furnace - The open furnace (Figure 2-3) has a water-cooled canopy hood, normally located 6 to 8 ft above the furnace crucible rim. The large opening between the furnace crucible and hood permits large quantities of ambient air to be drawn into the air pollution control system, diluting the furnace off-gas by as much as 50 to 1.¹⁹ Carbon monoxide generated in the furnace is burned as the

air combines with the hot gases. High-energy venturi scrubbers, electrostatic precipitators and fabric filters have been used on open ferroalloy furnaces.¹⁹

Because of the relatively low particulate concentrations and a high proportion of submicron particulates, scrubbers must operate with pressure losses as high as 60 to 80 in. H₂O to achieve removal efficiency of 96 to 99 percent.¹⁹ The power required to operate high-energy scrubbers is equivalent to approximately 10 percent of that needed by the furnace itself.¹⁹

Only two modern electrostatic precipitators are operating on ferroalloy furnaces in the United States. Both are installed on open furnaces producing chrome alloys. Most fumes from ferroalloy furnaces do not have proper electrical resistivity for satisfactory precipitator operation, unless the gases are humidified and conditioned with agents such as ammonia, or their temperatures are maintained above 500°F.¹⁹

Fabric filters are usually used with open furnaces. The most common type in the United States is pressurized (fan on the inlet) and exhausts through an open top or monitor. Open grates at the bottom of the baghouse permit cooling by natural convection. If the gas must be cooled before it enters the baghouse, this is achieved with radiant coolers or by dilution with ambient air. Cooling with water

sprays is much less common. Both felted and woven fabrics of many different materials have been used. Cleaning of the bags may be done by either reverse air or mechanical shaking. Air-to-cloth ratios vary between 1.2 and 2 acfm/ft² of cloth area. Because the particulate matter has both a high proportion of submicron particles and a high electrostatic charge, the pressure drop across a filter fabric is relatively high, 10 to 18 in. H₂O.¹⁹

2.1.6.2 Semienclosed Furnace - The semienclosed furnace (Figure 2-4) has a water-cooled cover which seals all but the annular spaces around the three electrodes through which raw material is charged. Since very little air enters the furnace, the gases it emits are rich in carbon monoxide.¹⁹

Wet scrubbers are the most common air pollution control devices applied to semienclosed ferroalloy furnaces. Both multistage centrifugal scrubbers and venturi devices are used. Centrifugal scrubbers are generally limited to a maximum air flow of about 2800 acfm, sufficient for a medium-size semienclosed furnace. For larger furnaces, parallel centrifugal scrubbers or venturi scrubbers may have efficiencies of up to 99 percent. Venturi scrubber efficiencies are higher, but so, too, are their power and water requirements. Pressure losses of up to 80 in. H₂O are common in venturi scrubbers controlling emissions from semienclosed furnaces.¹⁹

No electrostatic precipitators or fabric filters have been installed on semienclosed furnaces.

2.1.6.3 Sealed Furnace - The sealed furnace (Figure 2-5) operates in a manner similar to that of the semienclosed furnace, except that packing is used to seal around the electrodes and charging chutes. A slightly positive pressure is maintained in the furnace to prevent air leakage into it. Gas volumes to the control device are minimal and can be as little as 2 to 5 percent of those from an open furnace.¹⁹

The wet scrubber is the most common device used to control air pollution from sealed furnaces. Both multistage centrifugal and venturi scrubbers are used. Their efficiency and energy requirements for control of sealed furnaces are similar to those of semienclosed furnaces.¹⁹

Only one sealed ferroalloy furnace is known to use a fabric filter for air pollution control. The baghouse is a closed suction type, cleaned by reverse gas flow. Air-to-cloth ratio is about 1.5 acfm per/ft² of cloth area. Gas from the furnace is treated in radiant coolers before entering the baghouse. Added efficiency can be obtained by running water over the coolers.¹⁹

No applications are known in which electrostatic precipitators alone are used with sealed ferroalloy fur-

naces. However, systems consisting of two venturi scrubbers and a wet electrostatic precipitator, all in series, have been used to control emissions from three sealed ferroalloy furnaces in Japan. The venturi scrubbers serve as pre-cleaners and gas conditioners and operate at relatively low pressure drops (about 36 in. H₂O). The precipitator removes about 97 percent (according to EPA tests) of the particulate remaining in the gas stream after it has been through the scrubbers.¹⁹

A list of U.S. ferroalloy furnaces, some with the associated particulate control devices, is presented in Appendix A-6.

2.2 COMPARISON OF VARIOUS FACTORS WHICH INFLUENCE CONTROL DEVICE COLLECTION

2.2.1 Selection and Evaluation

A number of factors must be carefully weighed in the selection of a control device for a specific process and for a specific plant. Some of these correlations are given in Table 2-6.

As to the suitability of any of the various control devices under consideration, the processes themselves often dictate which device should be used. If the basicity of a sinter plant product is high, for example, increased resistivity occurs because of the presence of lime. To achieve high removal efficiencies on high basicity sinter, a much larger precipitator collection surface is essential. In some cases, electrostatic precipitators have been replaced by wet scrubbers to overcome this problem. Increasing efficiency requirements and the move to industrial energy conservation may also influence the selection of the control device.

In addition to describing design and operation/maintenance characteristics of each control device, it is the intention of this document to compare the control devices on the basis of fractional efficiency performance, where possible.

Table 2-6. FACTORS BEARING ON CONTROL DEVICE SELECTION

Characteristics of particles and gas stream	Facilities, costs, legal factors
Particle characteristics	Plant facility
Electrical properties (precipitators only)	Waste treatment
Resistivity	Space restriction
Dielectric constant	Product recovery
	Water availability
Physical properties	Cost of control
Surface properties	Engineering studies
Abrasiveness	Hardware
Porosity	Auxiliary equipment
Density	Land
Shape	Structures
Hygroscopic nature	Installation
Adhesivity	Start-up
Cohesivity	Power
Chemical properties	Waste disposal or recycle
Ignition point (precipitators, fabric filters)	Water
Chemical composition	Materials
	Gas conditioning
Particulate concentration	Labor
Size distribution	Maintenance
	Taxes
Gas stream characteristics	Interest on borrowed capital
Flow rate	Depreciation
Temperature	Insurance
Process	Return on investment
Viscosity	Regulations
Chemical composition	
Acid constituents	Maximum particulate and SO ₂ emission rates allowed by
Alkaline constituents	Federal, state, and local
Sulfur oxide content	laws
Moisture content	

2.3 ELECTROSTATIC PRECIPITATORS

2.3.1 General System Characteristics

This section of the report is intended to provide the reader with insight into the major parameters that must be carefully weighed in the design of an electrostatic precipitator. The procedure is straightforward; given certain input variables (process application, process flow correlations and parameters, and applicable particulate emission standards) and applying experience and theory, one can arrive at a design that meets the criteria for efficiency and cost. This format is illustrated in Table 2-7.

Table 2-7. DESIGN PHILOSOPHY

System input	Basic design parameters	Specific design parameters	System output
Process application Process conditions Applicable emission standard	Total ACFM Total collection area Power density	Gas and dust characteristics Precipitator capacity Electrical/mechanical Electrical energization System performance	Overall and fractional mass collection efficiency Capital investment Annual cost

The process applications under consideration are open-hearth furnace, basic oxygen furnace, electric arc furnace, sintering and scarfing for the iron and steel industry, and electric arc furnace for ferroalloy production. The ferroalloys include ferrosilicon, ferromanganese, ferrochromium, and miscellaneous ferroalloys.

Section 2.1 gave some indication of emission characteristics as well as process descriptions. The incidence of usage of the devices, based on their technical feasibility and operating limits, (Sections 2.1.3 and 2.1.6) is also known. As far as possible, those limits will be clarified in the discussion that follows.

Since these industrial applications are essentially all retrofit pollution control systems (and therefore quite site-specific), and given their limited applications in the iron, steel, and ferroalloy industry compared with their use in the utility industry, it will be difficult to generalize about design philosophy. Furthermore, the variation in processes and emissions during individual process cycles can cause wide differences in performance.

2.3.2 Design Philosophy

It is assumed that the reader is familiar with ESP theory. However, a brief discussion of operating principles follows. Additional background information on precipitator operation is presented in Appendix C-2.

The theoretical collection efficiency of a precipitator is often determined using the Deutsch equation:

$$\bar{\eta} = 1 - \exp (-w A/Q)^{20}$$

A = total effective collecting electrode area (ft²)

Q = total gas flow rate (acfm)

w = effective migration velocity

This equation assumes that due to turbulent mixing, particulate concentration is uniform at any cross section perpendicular to flow in the precipitator.

The effective migration velocity is the terminal velocity of a charged particle in the boundary layer near the collecting electrode and is largely a function of five variables: particle size, current density in the inter-electrode space, applied voltage, gas composition, and gas temperature.

In order to use the Deutsch-equation, it is helpful to know empirically the value of w for any specific application, and even then problems arise because w is not constant; it has been shown to vary with precipitator length, efficiency, gas velocity, etc. Changes in particle size distribution as precipitation proceeds cause this variation in w .

A semiempirical variation of the Deutsch equation, proposed by Matts and Öhnfeldt,²¹ essentially removes the size dependence from w . The equation is: $\bar{n} = 1 - \exp(-w_k A/Q)^k$ where k is said to equal about 0.5 in most cases. The modified migration velocity, w_k , can be treated as independent of changing current and voltage levels, and particle size distribution within an ESP, as the precipitation

process proceeds in the direction of gas flow. However, changes in the properties of dust entering the precipitator (resistivity, size distribution) produce a change in w_k just as they also change the conventional w . Values of w_k range from between 1.6 and 1.9 ft/s at moderate resistivity levels (10^9 ohm-cm) where as for a very resistive dust (10^{11} - 10^{12} ohm-cm) it may approach 0.5 ft/s or less.

Precipitator sizing curves presented in this section use the modified migration velocity, and specific values of w_k can be computed from the SCA/efficiency curves for the various applications.

2.3.2.1 Basic Design Parameters - The objective is to determine from the process application, process conditions, and emission regulations the values for gas volumetric throughput (acfm), total plate collection area (ft^2), and power density (watts/ ft^2 of collecting surface). These three parameters form the basis for precipitator design.

The total gas volume is dictated by process and production level. Knowing the total acfm and the specific collection area (SCA, $\text{ft}^2/1000$ acfm), one can determine the total area required to meet an emission standard. The necessary equations are given below.

$$\text{SCA} = \frac{16.7 \ln^{1/b} (1 - \bar{\eta})}{w_k}$$

$$\bar{\eta} = (1 - \frac{C_o}{C_i}) \cdot 100$$

where

b = slope of line (reference line slope = 0.5)

$\bar{\eta}$ = Overall mass collection efficiency, percent

w_k = Modified migration velocity, ft/s

C_o = Allowable outlet grain loading, grains/DSCF*

C_i = Inlet grain loading, grains/DSCF

ln = Natural log

State emission regulations have become much more sophisticated often specifying allowable emissions in pounds per hour and grains/ft³ as a function of the weight of raw material processed.

Where "equivalent opacity" is used as a standard, the presence of fines, although representing a small weight fraction, may cause a visible plume. Depending on the opacity standard, a visible plume may not be acceptable. Estimates of the required concentration to meet opacity codes can be made.

The following excerpt from the State of Pennsylvania Department of Environmental Resources Rules and Regulations is given as an illustration of current standards.²²

* DSCF = dry standard cubic foot.

PARTICULATE MATTER EMISSIONS

123.13 (b) Processes

"No person shall cause, suffer, or permit the emission into the outdoor atmosphere of particulate matter from any process" (examples of which are listed below) "at anytime either in excess of the rate calculated by the formula" (presented below) "or in such a manner that the concentration of particulate matter in the effluent exceeds 0.02 grains per dry standard cubic foot, whichever is greater."

Process	Process factor, F (in pounds per ton)
Primary iron and/or steelmaking	
Sintering windbox	20 (dry solids feed)
Steel production	40 (product)
Scarfig	20 (product)

Formula for Particulate Emission Limitation

$$A = 0.76 E^{0.42}$$

Where

A = Allowable emissions in pounds per hour

E = Emission index = F x W pounds per hour

F = Process factor in pounds per unit and

W = Production or charging rate in units per hour

Opacity cannot exceed 20 percent for a period or periods of more than 3 minutes in any one hour, or exceed 60 percent at any time (unless uncombined water is the only reason for failure to meet opacity limitations).

Power Input

The third basic design parameter is the power density required to establish the optimum voltage-current characteristics of the corona, given the amount of dust entering the precipitator. Power density is a function of electrical

resistivity, particle size characteristics and distribution, gas loading and composition, gas temperature, and gas pressure. It is often conveniently linked with resistivity, such that for a moderate resistivity of 10^9 ohm-cm a typical value will be approximately 2.5 watts/ft². For a high resistivity application the design value will be in the neighborhood of 0.5 to 1.0 watts/ft².

The selection of power density is often conveniently based on resistivity of the dust (which is principally iron oxide). Table 2-8 illustrates a general correlation between power density and dust resistivity.

Table 2-8. DESIGN POWER DENSITY

Resistivity (ohm-cm)	Watts/ft ² of collecting plate
10^{4-7}	4.0
10^{7-8}	3.0
10^{9-10}	2.5
10^{11}	2.0
10^{12}	1.5
$>10^{13}$	≤ 1.0

Operating voltages may range from 25 to 45 kV (typically 40 kV) for 9-in. plate spacing. Current densities typically range from 0.04 to 0.07 mA/ft² for iron and steel application except for electric arc furnace applications, where the range may be from 0.05 - 0.10 mA/ft². These

values are not constant for each point in the precipitator. At the inlet section, where dust loading is greatest, voltage-current characteristics will be significantly different from those at the outlet.

It appears that resistivity plays a significant role in selection of w_k and power density, yet there is no precise method of predicting resistivity from the material entering the furnace, process, or from the process conditions.

2.3.2.2 Specific Design Parameters - Table 2-9 is a compilation of design parameters and input variables grouped in logical categories.

Precipitator Size

One of the first structural parameters to be determined is the width of the precipitator(s). This value is dependent on the total number of ducts as determined from the following equation.

$$\text{Total no. ducts} = \frac{\text{ACFM}}{(\text{T.V.}) (60) (\text{P.S.}) (\text{P.H.})} \quad \text{Eq. 1}$$

where

ACFM = total gas volumetric throughput, acfm

T.V. = gas (treatment) velocity, fps

P.S. = plate spacing, ft

P.H. = plate height, ft

Treatment velocity (T.V.) is a function of dust resistivity.

Table 2-9. DESIGN PARAMETERS AND DESIGN

CATEGORIES FOR ELECTROSTATIC PRECIPITATORS

Dust Composition

Fe	FeO
SiO ₂	Al ₂ O ₃
MgO	CaO
Na ₂ O	K ₂ O
ZnO	P
S	Mn
C	Pb
Cu	Alkali
Zn	

Precipitator Capacity

Number of precipitators
 Number of chambers (units)/precipitator
 Number of ducts/chamber (unit)
 Duct spacing
 Plate height
 Treatment length
 Section lengths and total number of each (per precipitator)
 Collecting area
 Number of electrical sections parallel to gas flow (per precipitator)
 Number of electrical sections across gas flow (per precipitator)
 Number of hoppers parallel to gas flow (per precipitator)
 Number of hoppers across gas flow (per precipitator)

Rapping, Electrodes, etc.

Type of discharge electrode
 Ft² discharge electrode/vibrator or rapper
 Type of discharge electrode vibrator or rapper
 Type of collecting electrode
 Ft² collecting electrode/rapper
 Type of collecting electrode/rapper

Electrical Energization (of each electrical section)

Watts/ft² of collecting electrode
 Ft² of collecting electrode/transformer-rectifier
 Mode (switching)
 Corona kilovolts
 Milliamperes/1000 ft² of collecting electrode
 Milliamperes/transformer-rectifier

Performance-Related Parameters

Gas flow	Overall mass collection efficiency
Gas temperature	Fractional mass collection efficiency
Gas (treatment) velocity	Inlet grain loading
SCA	Outlet grain loading

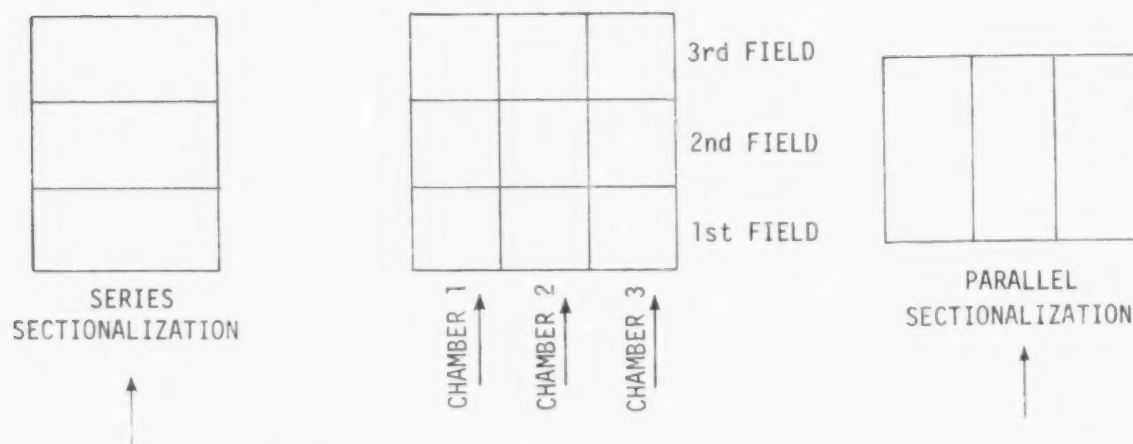
For open hearth furnace, basic oxygen furnace, and sintering applications the precipitator treatment velocity ranges from 3.5 to 5.5 ft/s. Electric arc furnace precipitators (primarily for ferroalloy production emissions) have treatment velocities in the range of 2.5 to 4.0 ft/s, whereas scarfing ranges from 4.0 to 5.5 ft/s. Since these figures are historical and do not entirely correspond to more recent stringent emission standards, the general range of 3.0 to 5.5 ft/s may be considered typical. In general, the more resistive the dust, the more desirable it is to maintain a longer treatment time, i.e., lower treatment velocity.

Plate spacing is more or less fixed by the manufacturer of the precipitator, depending on his experience with (1) the various process applications and conditions; (2) suspected velocity distribution across the precipitator; and (3) the type of plate. Plate spacing usually ranges from 6 to 15 in. For control of particulate emissions from the waste gas of a basic oxygen furnace, the inlet often has a larger plate spacing (~ 11 in.) than the outlet (~ 9 in.). This is due to the high grain loading (2-10 grains/DSCF) and the fact that oxygen lancing produces a large number of fine particles.

Plate height is determined by the necessity of simultaneously maintaining the required treatment velocity and an

adequate aspect ratio. The aspect ratio is defined as the ratio of the length of a precipitator (collecting plate dimension in direction of gas flow) to its height. Historical data indicate that it can vary from 0.75 to 1.5. The practical limitations on plate height imposed by structural stability requirements are obvious. Each manufacturer limits plate heights in accordance with the overall design.

Given the total number of ducts, one can calculate the width of the precipitator. What is required now is a description of the sectionalization of the precipitator, whether it be chamber-wise (across the gas flow), field-wise, also known as series sectionalization (in the direction of gas flow), or both. Fig. 2-6 shows all three types of sectionalization.



SERIES AND PARALLEL SECTIONALIZATION
(DIRECTION OF GAS FLOW
INDICATED BY ARROW)

Figure 2-6. Sectionalization of a precipitator

A practical approach from the standpoint of energization and reliability is to limit the total number of ducts per chamber. The number of chambers in a precipitator is determined by the number of ducts, which itself is determined from Equation 1 and its associated criteria. The number of precipitators needed will depend on the degree of reliability required, space limitations at the plant site, and the relative ease with which the effluent gas can be distributed to the precipitator(s).

The second general design equation provides a guide to the design length of the precipitator. As mentioned previously, the length is dependent on the selection of treatment velocity, plate spacing, plate height, gas volumetric throughput, and total collecting surface.

Eq. 2

Treatment Length =

$$\frac{\text{Total collecting surface}}{(\text{no. pptrs.}) (\text{No. chambers/pptr}) (\text{no. ducts/chamber}) (\text{P.H.}) (2)}$$

The design treatment length will be determined by selection of an integral value of standard section (field) lengths that may be offered by the precipitator manufacturer. If it is found, for example, that four fields are required, two of one length and two of another, structural considerations such as hopper spans may determine the positioning of the

fields in the direction of gas flow. The size of the transformer-rectifier (T-R) sets is selected to provide lower current density at the inlet.

A mechanical section resulted from a chamber-wise and field-wise sectionalized electrostatic precipitator. Hopper selection is based on the size of the mechanical sections and the suspected inlet grain loading.

Electrical/Mechanical Components

The geometry of the discharge electrode (fine, barbed, rigid, etc.) will determine corona current-voltage characteristics. The smaller the wire or the more pointed its surface, the greater the value of corona current for a given voltage. However there are problems with very fine or exotic wires, such as the potential for breakage and possible dulling of spliced points with wire. A standard wire has a diameter of 0.109 in.

Typical values for length of discharge wire per vibrator or per rapper can range from 2500 to 3500 ft. The number of square feet of collecting surface per rapper usually varies from 2000 to 3000.

Baffles provide stiffness to the collecting plant and create a region of low turbulence to minimize reentrainment of dust, particularly during rapping. Although a variety of plates are available, their fundamental characteristics are not substantially different.²³

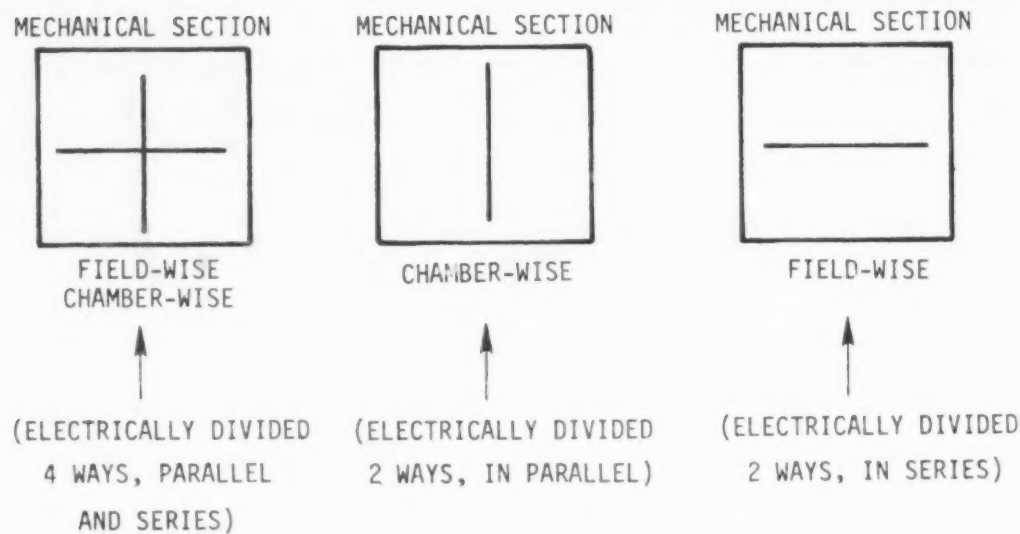
Rappers are either pneumatic, electromagnetic, or mechanical. Single-impact (magnetic-impulse, gravity-impact) rappers are often used. Rapping intensity is determined by the height of the rapper when released from its elevated position and by plunger weight, which may be from 8 to 32 pounds. The frequency of rapping is determined empirically by observing the values of opacity and overall mass collection efficiency, measured while intensity of rapping is varied.

Mechanical rappers are attached to a rotating shaft and are lifted by this means. Impact is usually provided in a horizontal direction. Intensity and frequency of raps are determined by the weight of the rapping hammers and by shaft speed, respectively.

Electrical Energization

The way in which a precipitator is energized has a great effect on its performance. This decision is probably as site-specific as it is process-specific. In any event, the same questions addressed in utility applications must be examined for industrial applications. These include the number and size of T-R sets, the number of electrical sections, degree of high-tension sectionalization, half wave-full wave (HW-FW) operation, and changes in voltage-current characteristics as precipitation proceeds in the direction of gas flow.

A mechanical section by definition may become an electrical section (bus section) if it can be separately energized. Within an electrical section one may have a chamber-wise or field-wise high tension split, or both (see Figure 2-7).



(DIRECTION OF GAS FLOW INDICATED BY ARROW)

Figure 2-7. High tension splits.

The advantages of splitting a mechanical section electrically both chamber- and field-wise are directly translatable in terms of increased reliability and, of course, in terms of increased cost. For the applications under consideration, both inlet and outlet sections are often split across the direction of gas flow (chamber-wise). In this configuration, the effect of temperature and dust loading variations across the precipitator because of poor gas distribution are minimized. This has the added advantage of increased reliability at the inlet, which is often in the half wave mode. If one bus section fails, a jumper cable can be engaged to apply full wave to the "companion" bus section, thereby preventing that bus section from failing.

Reliability is defined not only in terms of sectionalization of a given collection area, but also in respect to additional collection area or electrical fields. The degree of reliability can be defined in terms of redundant capacity, which is a function of anticipated failures in sections of the precipitator and time between maintenance periods. Redundancy may be defined as that additional area in a precipitator that compensates for an anticipated "normal" level of unavailable collecting area. It is clear that in order to achieve a reliable yet cost-competitive design, detailed information on dust characteristics are needed,

along with a clear understanding of the effect of process variations on precipitator performance.

The basic consideration in energizing the precipitator is to maximize the power input to achieve the highest collection efficiency from a given collection area. The decision on the degree of sectionalization, however, is made quite independently of the way in which the precipitator is to be energized. The number, size, and mode of operation (HW or FW) of the T-R sets can be manipulated to provide the required current density within each bus section of the precipitator. A commentary on the selection of HW or FW operation is presented below.

In the spark-limited operation, half wave allows time during the "off" half cycle for recovery from the sparking condition (spark quenching). Complete decay of the charging field and of collection efficiency during the "off" half cycle is avoided because of capacitive effect of high-resistivity dust, which tends to maintain the field potential.

In cases where the resistivity of the dust has been reduced, i.e., because of increased temperature of operation the capacitive effect of the dust is also reduced. Thus the charging field decays more in half wave than in full wave.

The selection of the mode of operation is rather site-specific, and the variability of performance measurements in full-scale precipitators may outweigh any differences due to operation in either half wave or full wave. For the processes under consideration, half wave historically has often been used in the inlet fields and full wave in the outlet fields.

In summary, it should be clear that the philosophy of precipitator sectionalization and energization is based on maximizing power input to the precipitator to achieve the highest efficiency from a given collection area, while minimizing decreased performance resulting from the various possible failure patterns. The reliability of precipitator performance is a function of process flow conditions and dust characteristics, reliability requirements, and the designer's experience. The way in which a precipitator is energized depends on the sectionalization configuration and on the current density to be supplied to each bus section, as determined by chemical and physical characteristics of the dust, by dust loading, and characteristics of the gas stream. The number, size, and mode of operation of the T-R sets can be fitted to the sectionalized configuration after the selection of bus section design has been established.

2.3.3 Correlations

The preceding discussion of precipitator design shows that three parameters are of central interest: gas volumetric throughput (acfm); total collecting area (ft^2); and power density (watts/ft^2 of collecting surface). The graphical correlations discussed in this section relate these basic design variables by process application. As indicated earlier, the designer's judgment, experience, and understanding of precipitator theory allow him to select the values of overall mass collection efficiency, SCA, and power density required for given process conditions and emission standards. A word of caution is needed, however. It is not intended that the broad-based approach presented here should provide information that can be directly applied to a specific site or installation. A number of highly practical points must be considered, such as design features to control and minimize large-scale turbulence, gas sneaking, and particle reentrainment in the precipitator.

The design and sizing of electrostatic precipitators are based both on a theoretical understanding of the control device and on past field experience. In the present work, the objective is to justify some typical design trends that have been established for precipitator sizing in the steel and ferroalloy industry.

The processes included in the present discussion are:

- (1) Basic oxygen furnace (BOF)
- (2) Open hearth furnace (OHF)
- (3) Electric arc furnace (EAF)
- (4) Sintering Process w/mechanical collector
- (5) Sintering Process w/o mechanical collector
- (6) Scarfing Process

Some typical operating data from the literature for these processes has already been shown in Table 2-1. Very limited operating data on precipitator performance have been obtained. What information is available, however, is presented to support existing design trends.

Figure 2-8 shows representative sizing curves used for the wire plate-type precipitator in the iron and steel and ferroalloy industries. The reference line has as its basis the modified Deutsch equation. In interpreting these data the objective will be to explain the effect of different input variables on precipitator design and to justify the relative position of basic design correlations; viz. SCA versus overall efficiency. Those precipitator parameters which require special attention are:

- (1) Particle size distribtuion
- (2) Inlet grain loading
- (3) Flue gas temperature

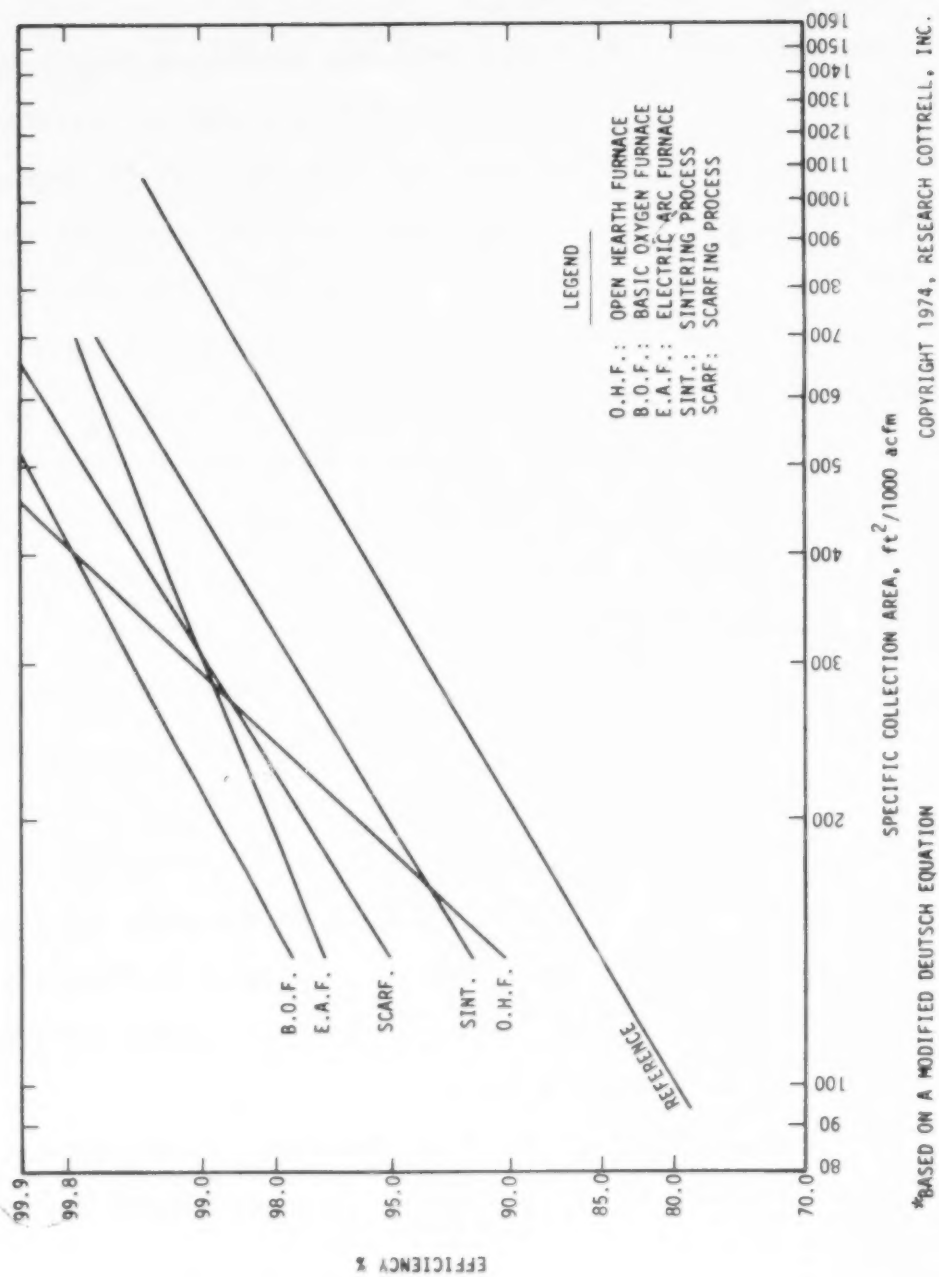


Figure 2-8. Selected precipitator correlations*.

- (4) Particle resistivity
- (5) Gas velocity
- (6) Gas treatment length

The information in Table 2-10 was extracted from Figure 2-8 to help identify the relative difficulties in collecting process fumes from the various applications. At 99 percent overall efficiency, it is seen that sintering requires the largest SCA at 455, BOF the smallest at 215. Electric arc furnaces, open hearth furnaces, and scarfing all having SCA's in the vicinity of 300. In explaining these design trends, it will be of interest to consider the effects of particle size distribution and of inlet grain loading on the precipitator size required to achieve 99 percent overall mass collection efficiency.

The particle size distribution characteristics derived from Weast et al.,⁶ along with selected average values for process variables based on manufacturers' data and information from the literature are given in Table 2-11. Information on mass mean diameters, geometric standard deviations, particle material density, inlet grain loading, and gas temperature is then used to generate the actual particle number density as seen at the precipitator inlet.

The above information is very important in estimating the relative magnitudes of the particle space charge densi-

Table 2-10. COMPARISON OF PERFORMANCE OF ELECTROSTATIC
PRECIPITATORS ON VARIOUS IRON AND STEEL APPLICATIONS^a

Efficiency, % Application	SCA (ft ² /1000 acfm) ^b		
	98.0	99.0	99.6
Sintering process	325	445	650
Electric arc furnace	190	310	540
Scarfig process	225	310	440
Open hearth furnace	245	295	340
Basic oxygen furnace	150	215	320

^a Manufacturers' data.

^b Although specific values of SCA are given, it should be clear that these are only some typical values within broad ranges of SCA's possible for these applications.

Table 2-11. SUMMARY OF EMISSION CHARACTERISTICS (STEEL/FERROALLOY APPLICATIONS)
USED TO DETERMINE NO. DENSITY - PARTICULATE SIZE DISTRIBUTION^a

Emission Source	Gas Temperature, °F	Volume Flow Rate, acfm	Uncontrolled Particulate Emission, gr/dscf	Particle Size ^b Distribution x d
Sintering w/ mechanical collector	350	106,000-2,000,000	0.6	7.7
w/o mechanical collector	350	106,000-2,000,000	6.0	70
Scarfing	125	20,000-120,000	0.55	NA
Open hearth furnace	575	50,000-200,000	0.7	0.21
Basic oxygen furnace	500	300,000-750,000	5.8	0.27
Electric furnace	800	175,000-200,000	2	0.80
				9.30

^a Manufacturers' data averaged for use in particle density - size distribution prediction model

^b Data derived from Ref. 23

ties, which strongly influence the electric fields at the collection plates. It is known that these collection fields directly influence particulate collection rates and hence the overall collection. The larger the space charge density, the higher the electric field is at the plate. This situation, however, weakens the field near the discharge electrode and suppresses the corona generation process, a phenomena commonly known as corona quenching. The particle size which contributes significantly to the particle space charge lies in the 0.05 to 1.0 μm range. In Figure 2-9, it can be seen that for BOF applications, the particle number densities in the 0.1 to 1.0 μm size range are at least an order of magnitude higher when compared with electric arc or open hearth furnace applications.

Other variables, such as particle resistivity and gas temperature, must also be considered. Assuming resistivities low enough not to cause back ionization (Figure 2-10),²⁴ it can be concluded that higher space charge density favors particulate collection in BOF applications relative to electric arc or open hearth furnace applications.

The size-number density distribution in the size range of interest (0.05 to 1.0 μm) is almost identical for electric arc and open hearth furnace applications. However, Table 2-11 shows that electric arc precipitators operate at

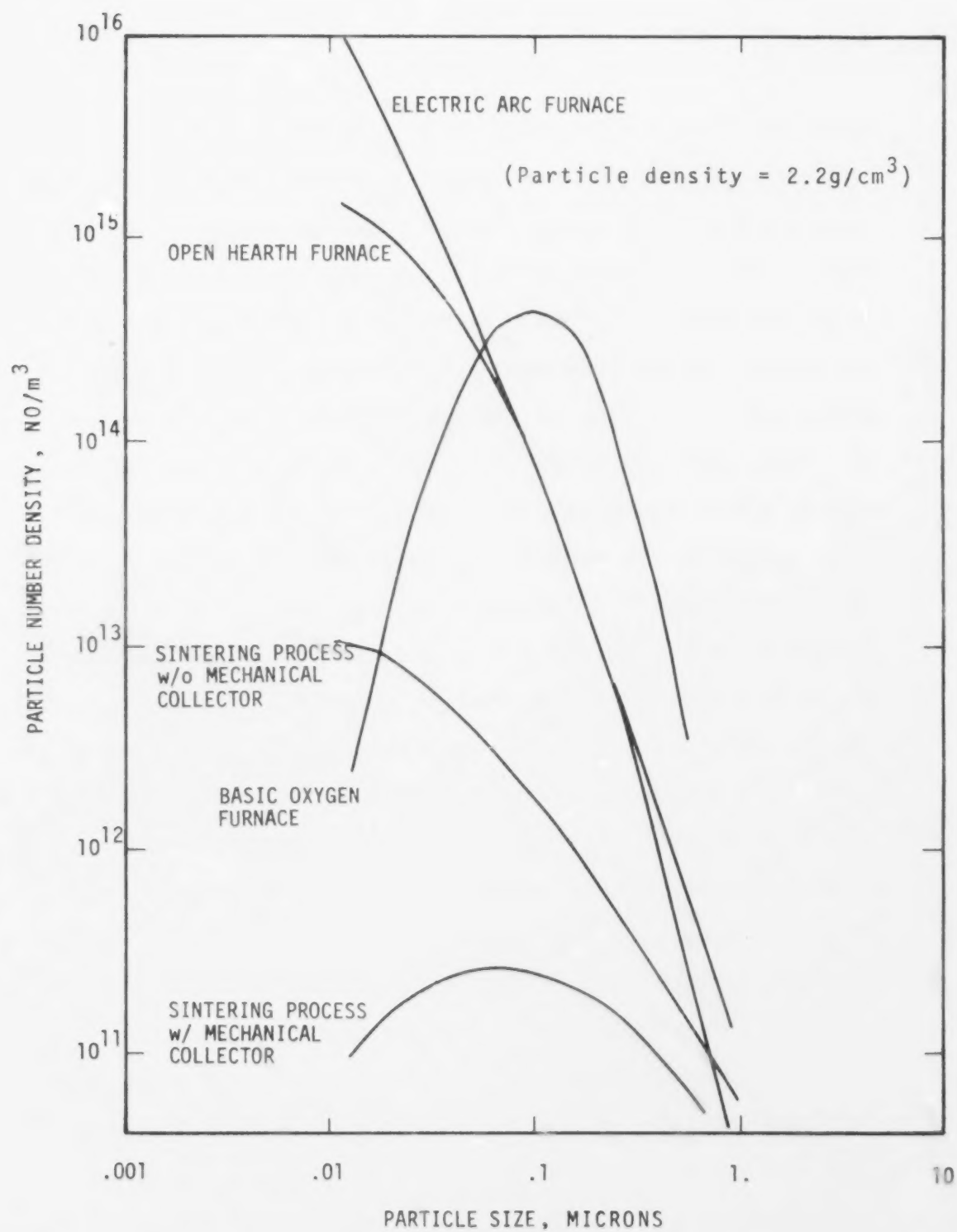


Figure 2-9. Size - No. Density Distribution For Ferroalloy Processes.

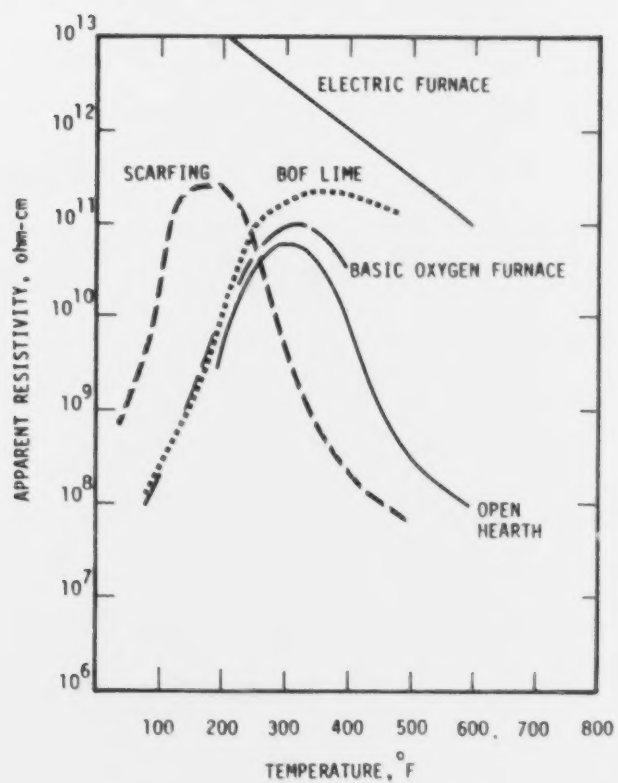


Figure 2-10. Apparent Resistivities of Metallurgical Dusts.¹²

much higher temperatures as compared with open hearth applications. This might have a favorable effect in decreasing the effective resistivity of the dust layer on the collecting plates, thereby enhancing the collection rate and efficiency of electric arc as compared with open hearth applications. Information on in situ resistivity measurements, however, is needed to support this point.

Figure 2-11 shows design and performance information gathered for the BOF application. The solid line refers to the existing design trend. Understanding that this line represents only one typical curve within a design band of values, the operational data from equipment manufacturers and Southern Research Institute,²⁵ generally support the design trend. The scatter in some of the test data points is probably due to the variability in the BOF process conditions. For example, moisture content could be low, resulting in high resistivity, or the gas temperature could be low enough to shift the apparent resistivity to a high value (Figure 2-10).

Figures 2-12 and 2-13 show the relationships between precipitator test and design data for open hearth and electric arc furnace applications respectively. Any changes in the fuel used during the open hearth refining process can affect the moisture content of the waste gases.^{26,27} Low

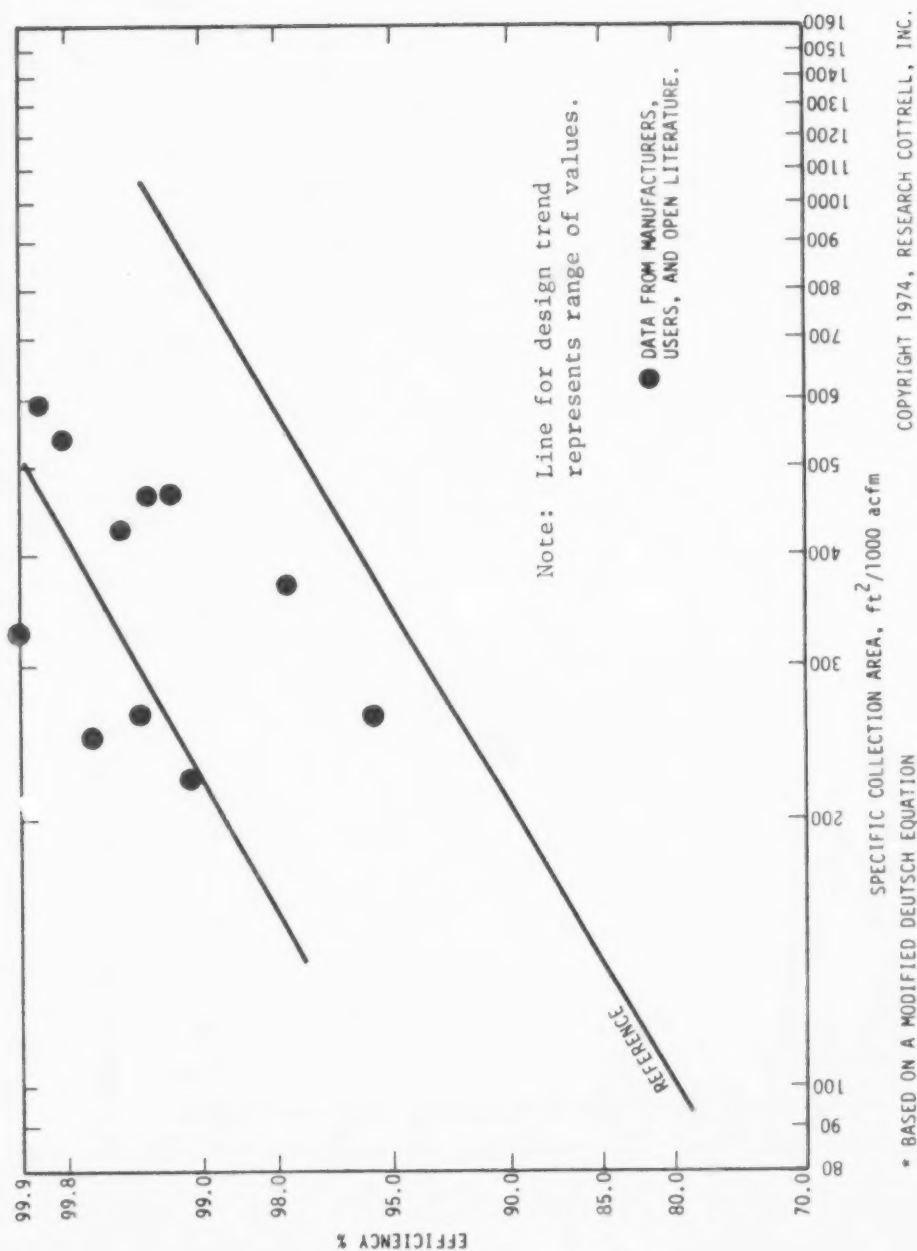


Figure 2-11. Selected precipitator correlations* for basic oxygen furnace.

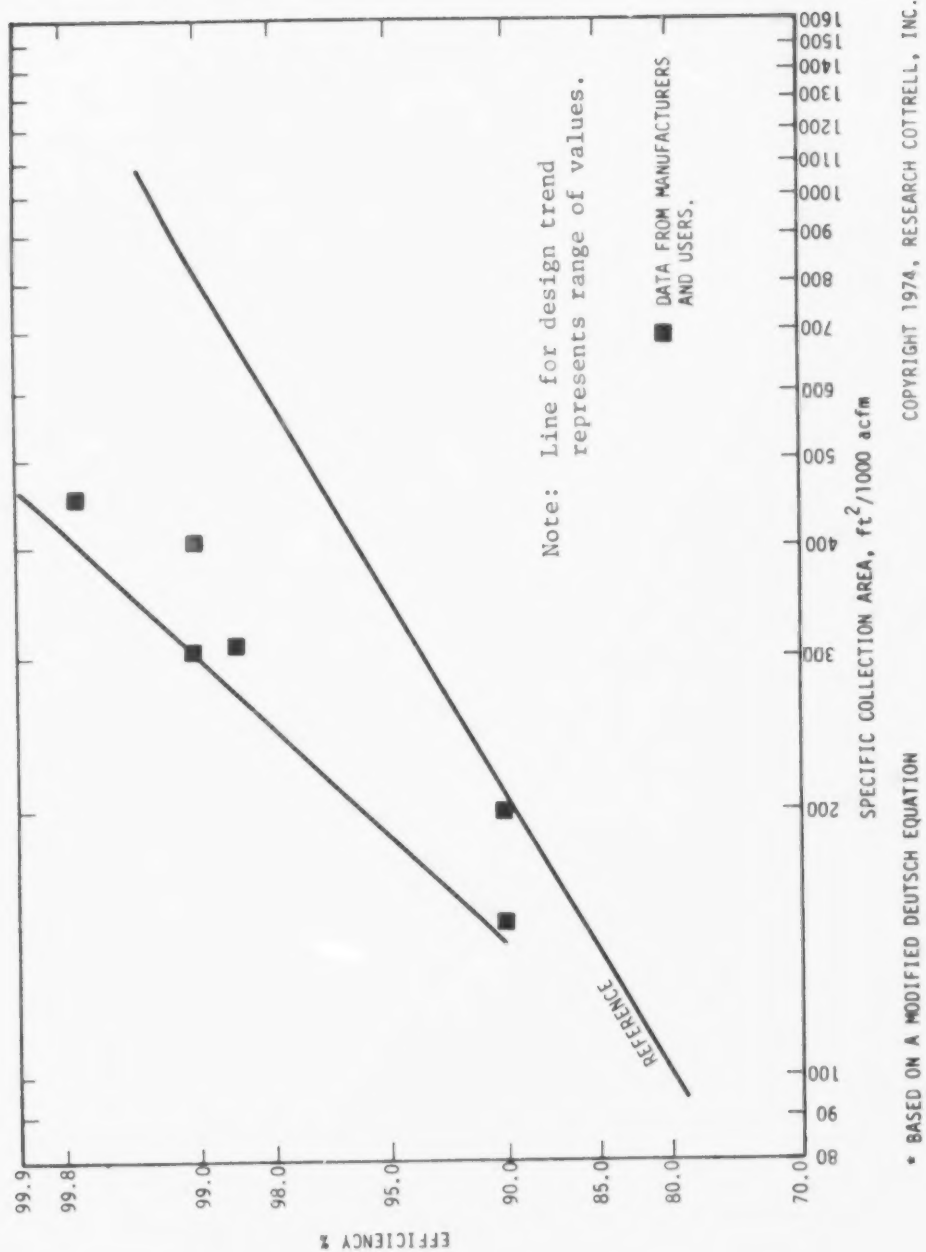


Figure 2-12. selected precipitator correlations* for open hearth furnace.

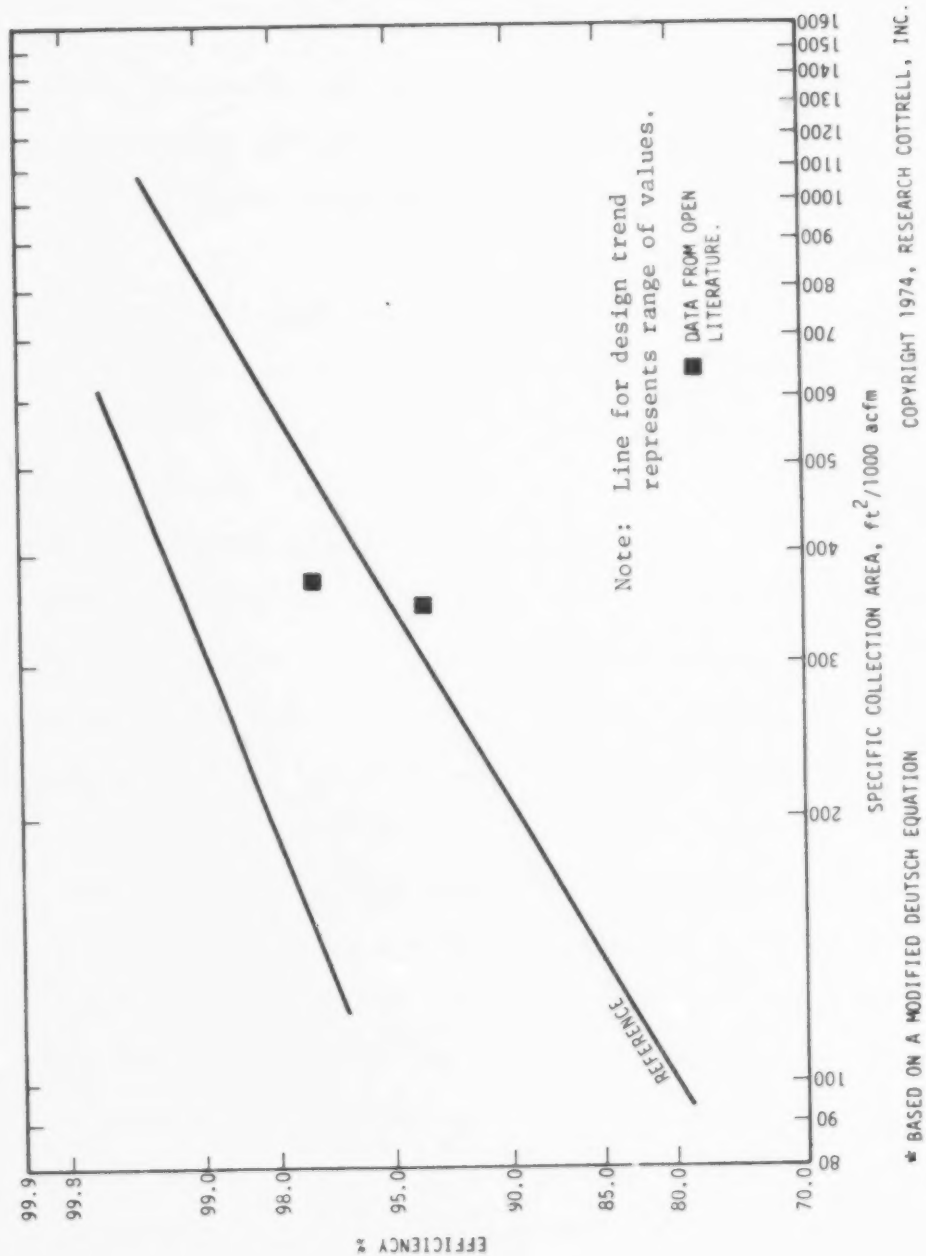


Figure 2-13. Selected precipitator correlations* for electric arc furnace.

fuel-firing rates and lower use of atomizing steam could lead to conditions more favorable for high apparent resistivity (Figure 2-10).

Since the use of electrostatic precipitators in electric arc furnace applications is very limited, there are an insufficient number of design and test data points to develop a meaningful commentary.

In the sintering process it appears that the particulate, which consists mainly of metallic oxides, silica, and limestone, is very resistive. As indicated in Figure 2-14, it may be on the order of 10^{11} and 10^{14} ohm-cm. This limits the current densities and the applied voltage at the discharge electrodes to avoid back corona formation. Thus, the particle charging process and the electric fields at the plates for particulate collection are marginal. This situation appears to be analogous to the behavior of high-resistivity fly ash found in some utility applications.

Figure 2-15 shows the available design and test data for electrostatic precipitators operating on sintering machines equipped with mechanical collectors. In general, fairly good correlation is noted. Of the applications considered in this study, sintering can have the widest variability in process operating conditions. The materials charged to the sinter machine can change during process

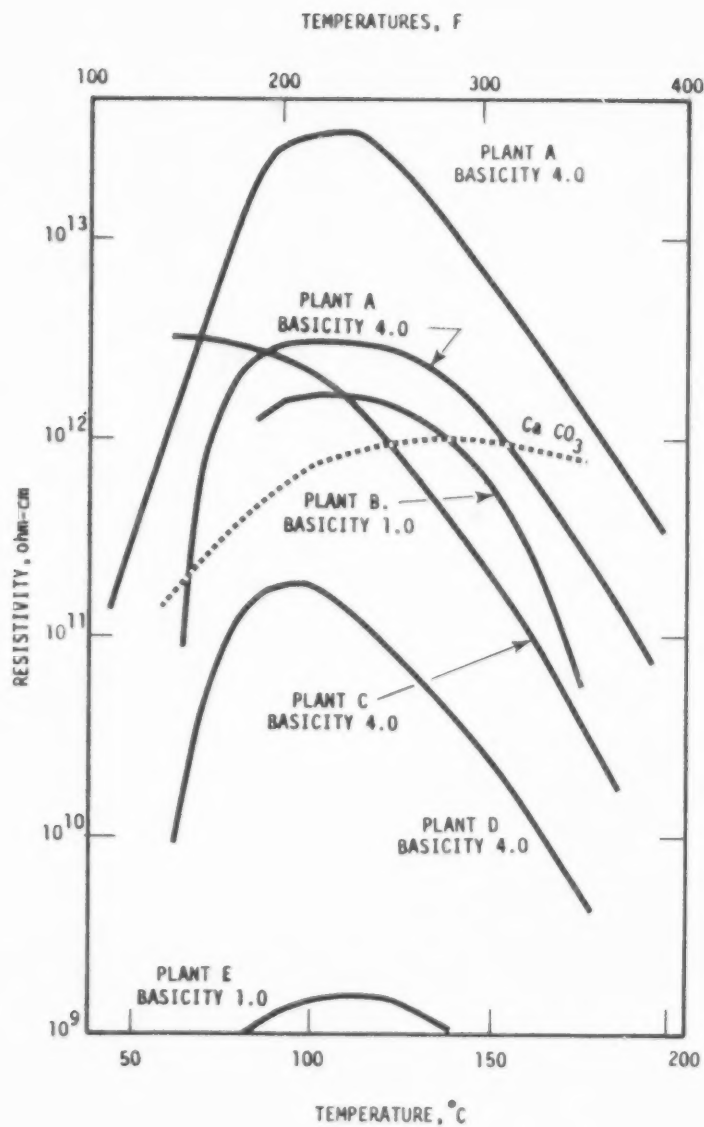


Figure 2-14. Effect of Temperature and Sinter Basicity on Resistivity of Sinter-Plant Particulate.²⁸

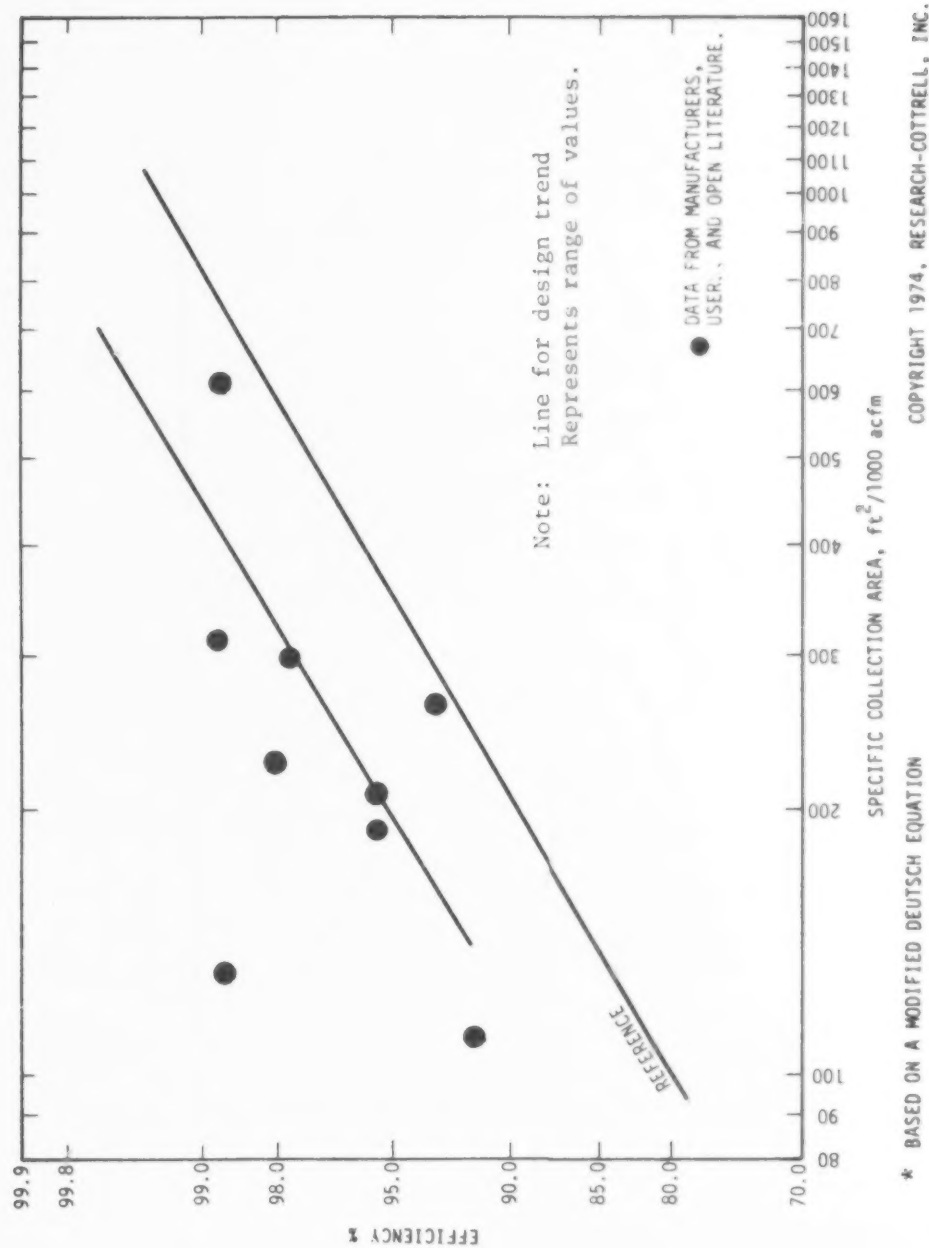


Figure 2-15. Selected precipitator correlations* for sintering process.

cycles, depending upon the availability of ore, ore fines, lime, etc. The properties of the dust are therefore affected.

No test data were available for scarfing. Typical operating gas temperatures lie in the range of 100 - 125°F. Resistivity-temperature data given in Figure 2-10 indicate apparent resistivity on the order of 10^{10} to 10^{11} ohm-cm. This value could be considered high enough to cause back ionization problems. Thus, again, precipitator performance can be limited by the operating voltage and the resulting current density, to avoid back corona formation.

2.3.3.1 Precipitator Capital and Annual Costs - Capital and annual costs were estimated for ESP's operating on the steel processes listed in Table 2-10. The SCA's and efficiencies presented in Table 2-10 were used as inputs for the computer model cost estimates, which are presented as a function of gas flow in Appendix B-1. Tables B-1-1 through B-1-5 summarize capital and annual costs for each process.

The total capital investment includes direct and indirect costs for the basic collector, auxiliaries, ducting, dust handling, and preparation of a dust disposal pond remote from the site. Direct costs are comprised of the equipment costs plus installation costs. Equipment costs are based on August 1976 numbers and escalated to June 1977, using "Chemical Engineering" cost indexes.

Indirect capital costs include the following items, each as a percentage of the total direct costs: Interest, 10 percent; engineering, 10 percent; field overhead, 10 percent; freight, 1.25 percent; off-site expenditures, 3 percent; taxes, 1.5 percent; spare parts, 1 percent; shakedown, 3 percent.

A contingency fee, is calculated as 20 percent of the sum of the direct and indirect costs, and the contractors fee is 5 percent of the sum of the direct, indirect, and contingency costs.

The annual costs consist of:

- 1) electricity usage (\$0.03/KWh)
- 2) water usage (\$0.30/10³ gal)
- 3) direct labor (\$9.00/man hour)
- 4) supervision (15% of direct labor)
- 5) labor and material (4.35% of capital investment)
- 6) supplies (15% of labor and materials)
- 7) plant overhead (50% of operating labor and materials)
- 8) payroll overhead (20% of operating labor)
- 9) dust disposal (10 mi. trucking distance @ \$0.15/ton mi.)
- 10) Fixed costs (18.6% of capital investment):
 - a) Depreciation (5%)
 - b) Interim Replacement (0.3%)
 - c) Insurance (0.3%)
 - d) Taxes (4%)
 - e) Capital Cost (9%)
- 11) Annual operating time is assumed to be 7000 hours/yr.
- 12) Useful life of the ESP is assumed to be 20 years

The capital and annualized costs of electrostatic precipitators can vary significantly with design philosophy and site-specific factors. Input factors which affect the costs presented here are the SCA and efficiency required, the gas flow rate, and the inlet and outlet dust concentrations. Gas flow rates for all of the processes range from 15,000 to 1,900,000 acfm at 300°F, the assumed temperature at the inlet to the ESP with the exception of scarfing, which was taken at 125°F. Costs for gas cooling prior to the ESP, were not estimated. Inlet dust concentrations were based on the uncontrolled particulate emission rates presented in Table 2-11. The outlet dust rates were calculated using the collection efficiencies of 98, 99, and 99.6 percent. The SCA inputs from Table 2-10 were increased by 5 percent to provide a measure of redundancy. In addition some of the actual required SCA values as calculated by the computer, were higher than the input values, in order to maintain a gas velocity of 4 ft/s and an aspect ratio of at least 1.20.

As would be expected, each set of cost curves shows an increase in capital and annualized costs with increasing gas flow and higher efficiencies. Some of the plots show a straight line relationship, but most of the lines show a gradual leveling off of costs at higher gas flows.

Most of the curves show costs that are closer together for smaller gas flows than for larger gas flows. Very small equipment installations tend to have relatively high capital costs, which do not correlate well with their size. In many cases small systems cost roughly the same regardless of the treated gas throughput. For the electric arc, sintering, and scarfing processes, the costs at the 99 percent level were not much greater than for the 98 percent level, but showed a significant increase at the 99.6 percent level. For the BOF and open hearth processes, the increase in cost between the 98, 99, and 99.6 percent efficiency levels, was relatively equal.

It is difficult to compare all processes at the same gas flow since the range of gas flows used for electric arc furnaces and scarfing are lower than for the other three processes. At 170,000 acfm, however, a gas flow at which costs can generally be compared for each process, sintering shows the highest range of capital costs, followed by the electric arc, BOF, scarfing, and open hearth processes, in that order. The spread of the capital costs for all processes is relatively narrow, at 170,000 acfm, at 3.25 to 6 million dollars, considering all three efficiencies used (98, 99, and 99.6%).

Annualized costs show a similar pattern to the capital costs, with the same order of processes from highest to lowest cost. The range of the annualized costs at 170,000 acfm considering all processes was 0.96-1.80 million dollars.

2.4 WET ELECTROSTATIC PRECIPITATORS

2.4.1 General System Characteristics

The use of wet electrostatic precipitators for emissions from industrial sources has been found for specialized applications.²⁹ These applications include acid mist, coke oven pushing operation, detarring operations. In the iron, steel industry, however, the principal use of wet precipitators appears to be in sintering, scarfing, and furnace, given the emission sources currently under study in this report.

Wet precipitators now in use consist of either a plate-type or pipe-type design. The pipe-type employs either a weir-overflow arrangement or a continuous saturation spray. Plate configurations usually have a combination of a saturation spray or a spray with intermittent wash.

Of all the wet precipitators used, the horizontal flow plate-type, with or without baffles (for gas distribution and additional saturation) and with continuous or inter-

millions of dollars, has been used in all three major applications mentioned above. In some of the plants the furnace was completely redesigned, whereas in others the furnace was modified to accommodate the use of the wet scrubber. The wet scrubber has been used in all three major applications mentioned above.

At the 25 domestic scrubbing machine manufacturers installations put into operation since 1971, 4 are of the plate-type and 21 of the pipe-type.

The wet scrubber has certain characteristics which, depending on the application, make it an attractive alternative to the dry scrubber, dry precipitator, or to fabric filter. The problem of high resistance is eliminated through the moisture conditioning effect and resistance is minimized. No tapping mechanism is required and pressure drop is low, typical of dry precipitators. The wet scrub system, has a high potential for corrosion and scaling, and requires a water treatment system.

2.4.2 Design Philosophy

As in the case of dry electrostatic precipitators, the design philosophy for wet precipitators is based on a few basic design parameters, the values for which are determined by consideration of process applications, process conditions, and the emission regulations to be met. Six basic design parameters have been identified in the literature and

are given below, 31, 32, 33

Collecting Area

Applying Voltage

Insulating Cupboard

Exhaust or Gas Inlet

Treatment Time

Local Average Velocity

The level of performance of a wet precipitator can be determined by using the standard Deutsch equation. The basis of this relation is the concept of migration velocity, as indicated by Burke, ³⁴ the effective migration velocity is a "catch-all" parameter and therefore includes operating parameters not indicated by the basic performance equation, namely:

$$\eta = (q/a) (0.308) \ln(c_o/c_L) \quad \text{Eq. 1}$$

where q = actual volumetric throughput, (actm saturated)

a = collecting area, (ft^2)

c_L = Inlet grain loading, (grains/SCF)

c_o = Allowable outlet grain loading, (grains/SCF)

w = Migration velocity, (cm/s)

c_o/c_L = Fractional loss of particulates or condensables

(0.308) = Conversion factor from ft/min to cm/s

The efficiency of the precipitator can be expressed then in the general form:

$$T = (T_0 + 80/84) 100$$

Eq. 2

of which substituting Eq. 1 into Eq. 2

$$T = 14 - 0.799/0.500 2) 100$$

Eq. 3

As a result of more sophisticated local, state, and Federal emission regulations in recent years,²⁹ combustibles have in some areas been added to the total particulate loading to be treated. Wet precipitators operate at saturated temperature and therefore are capable of removing organic materials with a particulate efficiency higher than that of most of the dry particulate precipitators.

The basic method in the industry has been "design by analogy," based on empirical application of the Deutsch equation. Recently some pilot plant studies have been conducted.³⁰ In general, however, design data are very sparse and very little data are found in the current literature. (See Table 1-13). To summarize, although the use of wet ESP's appears to be a viable technology for sintering, scarfing, and ferroalloy arc furnaces, as applied to this report, design data for wet ESP system are generally considered confidential and are not available because of intense competition between manufacturers with different wet ESP designs. Empirical application of the Deutsch equation in a design by analogy method has generally been used in the industry, although use of the Deutsch migration velocity is

Table 2-12. Typical Values and Ranges for Wet Precipitator
Basic Design Parameters

Parameter	Scarfig ^{a,b}	Sintering ^c
Collecting Area, ft ²	7500, 15000 (assuming 1 field per chamber)	25,200 (3 fields per chamber)
Operating Voltage, kV	40 - 60	55
Discharge Current, mA	90-90/1000 ft ²	1000
Liquid/Gas Ratio, gal/1000 acf		6.5
Treatment Time, s	10	8.79
Face Velocity, ft/s	1.5 (1.0-2.0)	2.73

a Derived from ESP Newsletter, April 20, 1977

b Ref. 31.

c Ref. 29.

subject to the same limitations as discussed in Section 3.2.2 for dry ESP's.

2.4.3 Correlations

Due to the general lack of data, no significant correlations could be developed. The only respondent in the survey reported an SCA requirement of 300 to 330 for an efficiency range of 98.23 to 99.27 percent.

Some cost data were available, however. Hill³¹ (Table 2-13) indicated that although the cost of wet electrostatic precipitator equipment can be as much as 45 percent greater than that for a high-energy scrubber, its installation and annual costs are far less. Therefore, on an annualized cost basis the wet precipitator is shown in this example to be economically superior to a high-energy scrubber.

Table 2-13. COMPARATIVE COST ANALYSIS OF WET ELECTROSTATIC
PRECIPITATORS AND HIGH-ENERGY VENTURI SCRUBBERS
FOR SCARFING PROCESS³¹

First year costs	High-energy scrubber	Electrostatic precipitator
Equipment	\$365,000.00	\$530,000.00
Installation	230,000.00	125,000.00
Operation	97,950.00	12,800.00
Total	\$693,450.00	\$667,800.00

Assumptions

Gas flow rate: 100,000 acfm
 Gas temp: 40-125°F, saturated
 Particle size: 98 percent sub-micron (iron oxide dust and fume)
 Inlet dust load: 2.0 gr/acf
 Desired collection efficiency: 99.5 percent

2.5 WET SCRUBBERS

2.5.1 General System Characteristics

The iron and steel industry's application of venturi scrubbers is more complicated than that situation in the electric utilities. Because of the intermittent nature of oxygen lancing in steelmaking processes, both the gas rate and the dust loading vary considerably during the process cycle. Moreover, the dust sizes and corrosive components of the furnace gases, which are often considered as key design considerations affecting the scrubber system cost, also vary with the furnace operating conditions.

The venturi scrubber system shown in Figure 2-16 serves as the basis for the following discussion on design parameters and cost.

2.5.2 Design Philosophy

In conventional terminology, the venturi scrubber is categorized as a gas-atomized spray scrubber. The collection process relies mainly on the acceleration of the gas stream to provide impaction and intimate contact between the particulates and fine liquid droplets generated as a result of gas atomization. Basically, this is a high-energy consuming device designed for high particulate collection. Typically, the pressure drop is on the order of 60 - 80 in. H₂O or more for iron, steel, and ferroalloy applications. Collection efficiency increases with the pressure drop and the liquid-to-gas ratio. However, there is an optimum L/G ratio above which the introduction of additional liquid is not effective at a given pressure drop. In this device the pressure drop can be increased by increasing gas velocity. Gas velocities could be as high as 40,000 ft/min, but this causes high wear.

To summarize, the key parameters affecting the particulate collection are:

- (a) Gas velocities and gas flow rates
- (b) Particle size distribution

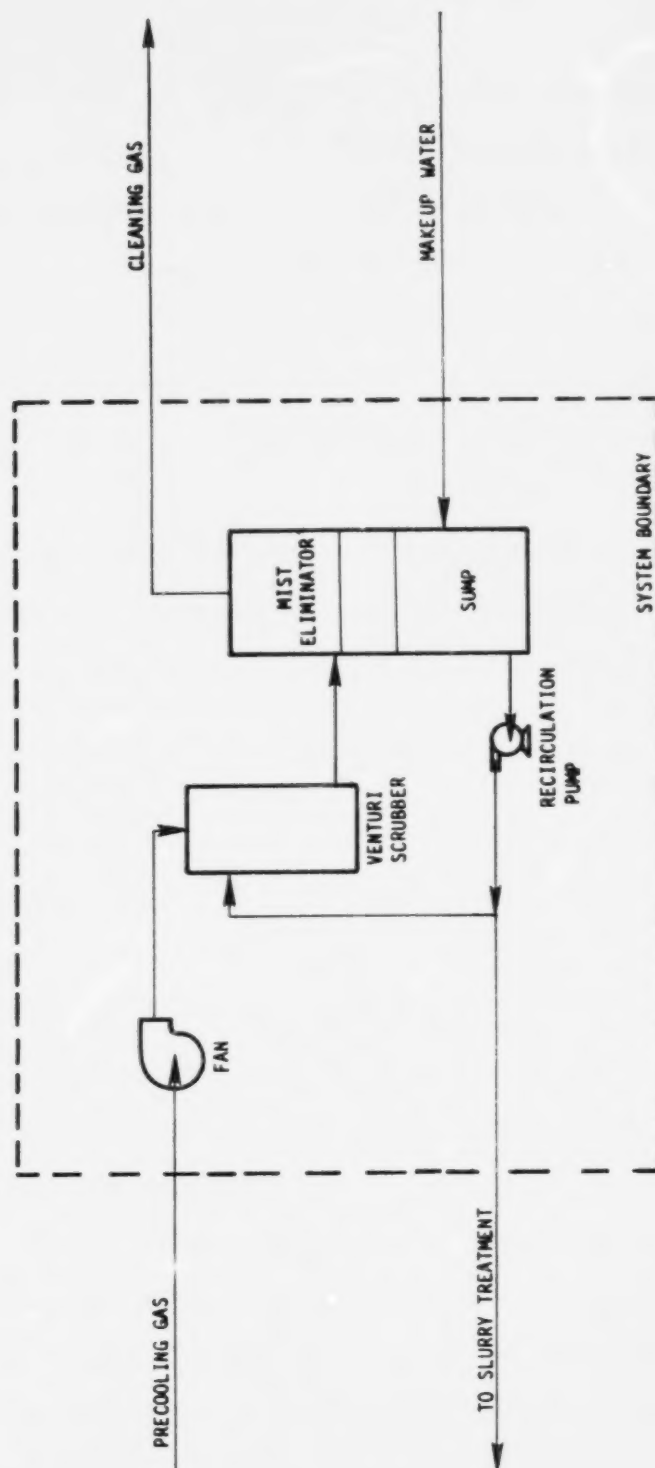


Figure 2-16. Venturi Scrubber System.

- (c) Pressure drop
- (d) Liquid-to-gas ratio

Besides these parameters, the following information is also required to justify the choice of equipment.

- (a) Gas handling capacity/module
- (b) Total number of modules required
- (c) Capital investment
- (d) Annual costs
- (e) Water requirement; water recirculation
- (f) Availability of the equipment or necessary downtime
- (g) Indication of fractional collection efficiency of the device
- (h) Total power consumption as a fraction of the generated power

Additional parameters to be used in the justification of choice of pollution control equipment may be found in Appendix B-2.

2.5.2.1 Velocity/Gas Flow Rate - Sizing a venturi scrubber is often based on the inlet gas velocity and its flow rate. Inlet gas velocity is usually about 60 ft/s while the inlet gas flow rate is dependent on the designed scrubber diameter. Typical scrubber diameters are under 10 ft.

Gas velocity through the venturi will decrease more at higher temperatures than at lower temperatures. Also, higher liquid-to-gas ratios are required for heat transfer

to higher temperature gases to reach saturation. If gas temperatures are in excess of 400°F, a gas prequencher is often required as in the case of basic oxygen furnace scrubber applications.

2.5.2.2 Liquid-to-gas (L/G) Ratio - The liquid-to-gas ratio typically varies from 2 - 15 gal/min per 1000 ft³/min and is basically a function of inlet gas temperature, inlet solids content, and method of water introduction.³⁴ At higher inlet gas temperatures, evaporation of the scrubbing liquor may occur at the point of liquid/gas contact. In the case of heavy inlet dust loading, the L/G ratio should be increased to minimize solids buildup and plugging of trains. Although pressure drop across the venturi is essentially independent of the particular design, the less efficient methods of water introduction will require additional scrubbing liquor in order to meet efficiency requirements.

2.5.2.3 Pressure Drop - The scrubbing design for a given application requires careful selection of the throat velocity and liquid-to-gas ratio to achieve the maximum collection efficiency for energy spent. Energy spent is often indicated by the gas pressure drop across the scrubber, which ranges typically from 60-80 in. H₂O for the applications considered in this report. In fact, the pressure drop is a function of the throat velocity and the L/G ratio. To

achieve a given pressure drop, numerous relationships between these two parameters can be used. However, only one set of conditions will yield the maximum efficiency for the energy spent. That one set of conditions is the only one which will create maximum droplet surface with a minimum liquid-to-gas ratio during atomization.

2.5.2.4 Particle Distribution - The particle size distribution in the inlet gas stream is a key factor in the process design. However, particle size distribution in a source gas often varies with process and operating conditions of the source gas. The fractional collection efficiency data on submicron particles is particularly difficult to obtain. When we are speaking of greater collection efficiencies, it should be understood that this means increased fractional collection efficiencies in the submicron particle size range.

2.5.2.5 Material Selection - Scrubber slurry as well as gas streams are often corrosive and erosive due to acid gases and abrasive solids content, respectively. Selection of suitable construction materials must be considered.

Stainless steel is sometimes necessary, especially at installations where SO_2 and fluorides are present. SO_2 is often present in ores and the fuel of sintering processes. Fluorides occur in open hearth furnace and electric arc furnace applications where fluorspar is added to the charge.³⁵

Where corrosion and abrasion resistance requirements exceed the limits of stainless steel, fiberglass reinforced plastic (polyester) may be used.

Abrasion-resistant liners are also needed to withstand high temperature and/or corrosion situations, such as where chlorides are present and/or where fluorides are found at elevated temperatures.

2.5.2.6 Mist Elimination - Mist eliminators are necessary to control undesirable emissions of liquid droplets from scrubbers, caused by atomization and carry-over of some liquid during scrubbing. Because of the solids in the scrubbing liquor, the entrainment of water droplets can cause system operating problems, not to mention liquid losses. Suspended or dissolved particles can cause solids buildup, and suspended solids can cause erosion of the mist eliminators. Increased pressure drop is one of the many problems caused by buildups.

2.5.2.7 Design Modules - Another difficulty in designing venturi scrubbers is the lack of a reliable design model to represent the actual system for particulate removal. Nearly all the published scrubber models show either by formulas or by design curves that the empirical correlations are based on inertial impaction or overall power input. Empirical models are often limited by empirical conditions. In other

words, both control variables and noncontrol variables vary within certain ranges for empirical models. Extrapolating the design data from empirical models, therefore, involves some risk. Moreover, particulate collection in a venturi scrubber is not only dependent on the particle size distribution, but also on particulate properties such as specific gravity, wettability, agglomeration, solubility in the scrubber liquid, etc.

The K-factor in Brink's model,³⁶ f-factor in Calvert's model,³⁷ and the β and γ constants in the Power-law model³⁸ are all empirical constants encompassing many of the above parameters upon which particulate collection depends. As to which model is suitable is a matter of judgment. In addition, other mechanisms such as diffusion may control collection of submicron particles.

2.5.3 Correlations

Research Cottrell prepared a set of scrubber correlations for steel/ferroalloy applications based on their model which was developed for some utility applications. The processes covered were electric arc, basic oxygen, and open hearth steel furnaces, ferroalloy arc furnaces, and sintering. The results of these correlations in all cases except for sintering, indicate that the conditions used as inputs, (i.e., particle size distribution) are beyond the limits for

which the model was designed. PEDCo used Calvert's model³⁷ and came to the same conclusions.

Research Cottrell's correlations are presented in Appendix B-3 for information purposes only. The overall mass efficiencies predicted by the computer performance model for the steel and ferroalloy furnaces are too low, considering the pressure drops at which they are calculated. The reasons for the low predictions of efficiency are discussed further in Section 4.2.2.3.

In general, however, Figures B-3.1 to B-3.9 show that the effect of pressure drop on the collection efficiency is uniquely strong, while the L/G ratio in the study limit shows no great effect. Theoretically, for a given particle size distribution, the collection efficiency is a function of the total droplet surface created by gas atomization. If the L/G ratio is too large or too small for gas atomization, the collection efficiency will decrease. Intuitively, in the neighborhood of the optimum L/G, the L/G should have little effect on the collection efficiency. Of course, other factors such as gas temperature, water injection technique, and scrubber configuration also affect the collection efficiency. However, in the strictest sense, these are not control variables.

2.5.3.1 Costs - Capital and annual costs have been estimated by Research Cottrell for use of a venturi scrubber on steel and ferroalloy processes. A list of assumptions used for the development of these costs, which were based on the computer performance model, is presented below:

Basis of the Performance and Cost Analysis

1. Major equipment included in the venturi scrubber system consists of a flooded disc scrubber and a mist eliminator with a sump tank, one forced draft fan with driver, and two slurry pumps with drivers. The auxiliaries included are ductwork, expansion joints, piping, and instrumentation.
2. The construction material for both major equipment and auxiliaries is carbon steel without linings. One exception is the throat of the venturi, which is made of an extremely high grade of alloy stainless steel.
3. The temperature of the flue gas is taken to be 300°F.
4. The total capital investment for the system consists of the major and auxiliary equipment costs, tax and freight (average), installation costs, engineering, and contingency costs.
5. The annual costs consist of:
 - (1) Fixed charges (15% of the total capital investment), including depreciation, interest, insurance and taxes.
 - (2) Maintenance (5% of capital investment), including materials and labor.
 - (3) Labor cost (\$ 9/man-h assuming 3500 man-h/yr required)
 - (4) Administration (10% of labor cost).

- (5) Water usage (\$.30 per 1000 gallons.)
 - (6) Electricity usage (\$.03/kWh).
 - (7) Overhead cost (10 % of the total cost of water, electricity, labor and maintenance).
 - (8) Annual operating time is taken to be 7000 hours/yr.
- 6. Cost estimates are based on the material and labor prices in the first quarter of 1977.
 - 7. Particulate properties (assuming a specific gravity of 3.0 grams/cm³; (see particle size distribution in Table 2-1, by Weast et al.²³)

The effects of pressure drop (or collection efficiency) on the capital investment are shown in Figures B-4.1a to B-4.9a, presented in Appendix B-4. These effects are due to the fan cost which is a function of pressure drop and gas temperature, in addition to the gas rate. Theoretically, for a system with high gas temperature and high efficiency of fine particulate removal, a gas precooler may be required for reducing the temperature effects on the scrubber performance as well as on the fan cost.

The materials of equipment construction, which depend on the gas properties, is another key factor affecting the capital investment. If the gas contains corrosive components, such as SO_x, Cl₂, etc. above a critical level, stainless steel should be used. In addition, pumps and pipes must have liners to provide protection against abrasion. With the additional costs for corrosion resistance

and abrasion resistance, the capital investment of a venturi scrubber system may be as much as two times more than that with the base material (carbon steel). However, since the types of liner materials that are used are so variable, costs were estimated for carbon steel only.

In Figures B-4.1b to B-4.9b, which represent annual costs for the venturi scrubber, it is shown that the electricity usage has a considerable effect on the total operating cost for each application. In fact, for high efficiency of fine particulate removal, most of the electricity usage is for fan operation. In comparison with the electricity usage, the fixed charges which include equipment depreciation, tax, insurance, and interest only play a minor role. However, in a system where a gas precooler and/or stainless steel equipment are required, the fixed charges increase sharply. The labor, maintenance, water, and overhead are grouped into the "others" category as shown in these figures.

2.6 DESIGN RELATIONSHIPS FOR FABRIC FILTERS

Fabric filters are basically simple devices. The removal of particulate from waste gases is accomplished by forcing the gases to flow through the fabric filter media, which removes the particulates by one or more of the following mechanisms:

- (1) Inertial impaction
- (2) Diffusion to the surface of an obstacle by Brownian diffusion
- (3) Direct interception because of finite particle size
- (4) Sedimentation
- (5) Electrostatic phenomena

Baghouses have been used successfully for control of particulate emissions on each of the above described processes. By "operating successfully" it is meant that:

1. The baghouse removes approximately 99+ percent of the material from the gas stream. No measured data are available to document this performance. Results are based on discussions with plant personnel.
2. The baghouse operates at a reasonable steady state pressure drop (3 to 12 in. H₂O).
3. The baghouse has reasonable filter life. Less than 1 yr would be unacceptable, while more than about 7 yr would be excellent.
4. No serious corrosion or erosion problems exist.

Although users in general are satisfied with overall baghouse performance (clean process area; no visible plume) and operational aspects (reasonable bag life, pressure drop, etc.), there have been cases of very expensive engineering lessons learned. One of these is described in case history of a user's experience with a large fabric filtration system, presented in Appendix B-5.

Parameters important to fabric filtration system design include air-to-cloth ratio, pressure drop, cleaning mode and frequency of cleaning, composition and weave of fabric,

degree of sectionalization, type of housing, and gas cooling. Baghouses are relatively insensitive to process variables such as chemical composition (providing that the correct bag fabric is chosen), particle size, electrical resistivity, etc.; thus, there tends to be very little substantial design difference from one application, or indeed from one manufacturer, to the other, when comparing baghouses with the same cleaning mechanism. Differences that do exist are generally related to maintenance (e.g., number of bag rows accessible from a given interior walkway; method of bag cuff attachment to cell plate; etc.).

Table 2-14 lists the pertinent baghouse design criteria for the applications treated in this report. Each of these criteria is discussed briefly below.

2.6.1 Air-to-Cloth Ratio

A major factor in the design and operation of a fabric filter, the air-to-cloth (A/C) ratio is the ratio of the quantity of gas entering the filter (ft^3/min) to the surface area of the fabric (ft^2). The ratio is therefore expressed as ft^3/min per ft^2 , or sometimes also as filtering velocity (ft/min). Most often only the first member of the ratio term is given, e.g., an A/C ratio of 1.5 implies $1.5 \text{ ft}^3/\text{min}$ per 1.0 ft^2 . In general, a lower ratio is used for filtering of gases containing small particles or particles that

Table 2-14. FABRIC FILTER DESIGN CRITERIA

	Sintering		Ferroalloy		Steel	
	Generally, No	Continuous automatic	Both, but suction preferred	Shaker, reverse air and pulse but shaker and/or reverse air used most	Wind box from 1.5:1 to 6:1 discharge at $\leq$ 3.3:1 for low ratio and $\leq$ 7.4:1 for high ratio	10-18 in. H ₂ O
Gas cooling required	Generally, No	Continuous automatic	Both, but suction preferred	Shaker, reverse air and pulse but shaker and/or reverse air used most	Wind box from 1.5:1 to 6:1 discharge at $\leq$ 3.3:1 for low ratio and $\leq$ 7.4:1 for high ratio	10-18 in. H ₂ O
Baghouse intermittent or continuous automatic	Continuous automatic	Both, but suction preferred	Shaker, reverse air and pulse but shaker and/or reverse air used most	Wind box from 1.5:1 to 6:1 discharge at $\leq$ 3.3:1 for low ratio and $\leq$ 7.4:1 for high ratio	10-18 in. H ₂ O	10-18 in. H ₂ O
Pressure or suction	Both, but suction preferred	Shaker, reverse air and pulse but shaker and/or reverse air used most	Wind box from 1.5:1 to 6:1 discharge at $\leq$ 3.3:1 for low ratio and $\leq$ 7.4:1 for high ratio	10-18 in. H ₂ O	10-18 in. H ₂ O	10-18 in. H ₂ O
Bag cleaning method	Shaker, reverse air and pulse but shaker and/or reverse air used most	Wind box from 1.5:1 to 6:1 discharge at $\leq$ 3.3:1 for low ratio and $\leq$ 7.4:1 for high ratio	10-18 in. H ₂ O	10-18 in. H ₂ O	10-18 in. H ₂ O	10-18 in. H ₂ O
Air to cloth ratio	Wind box from 1.5:1 to 6:1 discharge at $\leq$ 3.3:1 for low ratio and $\leq$ 7.4:1 for high ratio	10-18 in. H ₂ O	10-18 in. H ₂ O	10-18 in. H ₂ O	10-18 in. H ₂ O	10-18 in. H ₂ O
Pressure drop	10-18 in. H ₂ O	10-18 in. H ₂ O	10-18 in. H ₂ O	10-18 in. H ₂ O	10-18 in. H ₂ O	10-18 in. H ₂ O
Fabric Material Weight (oz/yd ²)	(Typical) Fiberglass 9	(Typical) Polyester 7	(Typical) Nylon 5.2	(Typical) Polyester 8.7	(Typical) Fiberglass 8.9	(Typical) Polyester 5.2
Permeability (cfm/ft ²)	45-60	-	20-35	30-40	-	15-25
Bag size (dia x length)	8 in. x 22 ft to 12 in. x 30 ft	6 in. x 15 ft	8 in. x 20 ft	8 in. x 20 ft	12 in. x 30 ft	8 in. x 20 ft to 12 in. x 30 ft
Pyramid or trough hopper	Trough-type preferred	Trough-type preferred	Trough-type preferred	Trough-type preferred	Trough-type preferred	Trough-type preferred
Collected material handling technique	Screw conveyors	Screw conveyors	Screw conveyors	Screw conveyors	Screw conveyors	Screw conveyors
Provisions for fire or explosion	Generally, No	Generally, No	Generally, No	Generally, No	Generally, No	Generally, No

may otherwise be difficult to capture. Selection of the ratio is generally based on industry practice or the recommendation of the filter manufacturer.

Design A/C ratios for the fabric filters now installed on iron and steel and ferroalloy electric arc furnaces range from 1.5 to 3.1.

For sintering the windbox air-to-cloth ratio is generally 1.5. However, ratios as high as 6 have been used; at the discharge, the low ratio is ≤ 3.3 and the high ratio is ≤ 7.4 . In general, air-to-cloth ratios are limited according to fabric type.

2.6.2 Pressure Drop

Pressure drop in a fabric filter is caused by the combined resistances of the fabric and the accumulated dust layer. The resistance of the fabric alone is affected by the type of cloth and the weave; it varies directly with air flow. The permeability of various fabrics to clean air is usually specified by the manufacturer as the air flow rate (ft^3/min) through 1 ft^2 of fabric when the pressure differential is 0.5 in. H_2O in accordance with the American Society of Testing and Materials (ASTM). At normal filtering velocities, the resistance of the clean fabric is usually less than 10 percent of the total resistance.³⁹ The spaces between the fibers are usually larger than the

particles that are collected. Thus the efficiency and low-pressure drop of a new filter are initially low. After a coating of particles is formed on the surface, the collection efficiency improves and the pressure drop also increases. Even after the first cleaning and subsequent cleaning cycles, collection efficiency remains high because the accumulated dust is not entirely removed.

The pressure drop through the accumulated dust layer has been found to be directly proportional to the thickness of the layer. Resistance also increases with decreasing particle size.³⁹ Even though several studies have been devoted to filtration theory, it is difficult to relate collection efficiency and pressure drop on an industrial scale. Maximum pressure drop on existing iron and steel and ferroalloy processes ranges from about 10 to 18 in. H₂O.

2.6.3 Cleaning of Fabric Filters

Various cleaning methods are used to remove collected dust from fabric filters to maintain a nominal pressure drop of 2 to 6 in. H₂O. These are shown in Table 2-15 and briefly discussed below.

Shake: Many mechanical shaking methods are in use. Most commonly, bags are shaken from the upper fastening. Several combinations of horizontal and vertical motion can be used. The bags may all be fastened to a common framework moving

Table 2-15. COMPARISON OF FABRIC FILTER CLEANING METHODS^a

Cleaning method	Uniformity of cleaning	Bag attrition	Equipment ruggedness	Type fabric	Filter velocity	Apparatus cost	Power cost	Dust loading
Shake	Average	Average	Average	Woven	Average	Average	Low	Average
Reverse air	Good	Low	Good	Woven	Average	Average	Med. low	Average
Plenum pulse	Good	Low	Good	Felt, woven	High	High	Med.	High
Pulse-jet	Average	Average	Good	Felt, woven	High	High	High	Very high
Vibration, rapping	Good	Average	Low	Woven	Average	Average	Med. low	Average
Sonic assist	Average	Low	Low	Woven	Average	Average	Med.	Med.

^a Based on data from Reference 39.

horizontally or the frame may have slight additional upward or downward swing, depending on the linkage holding the framework. The framework can also be oscillated vertically.

During the shake, the filtering should be stopped. Otherwise, the dust will work through the cloth, reducing the efficiency and possibly damaging the cloth by internal abrasion. An effective cleaning method involves a series of alternate flows and shakes. This gives a gentler treatment to the cloth in addition to the cleaning being uniform and thorough.

In a typical cycle, the inlet flow to the compartment is first dampered off by a timer. If necessary, the outlet vent is also closed (Figure 2-17). In the absence of an air lock between adjacent hoppers, it may be necessary to close a damper there to prevent the intrusion of dirty air from hoppers still operating. There should be zero forward pressure across the fabric during shaking, since otherwise dust will work through the fabric. The timer starts the shaker motor and the bags are shaken. Shaking continues for about 10 to 50 cycles, each cycle taking about 0.2 to 1 s. Then the timer may start a small flow of clean reverse air using an auxiliary blower for 10 to 20 seconds. The shaking may be repeated, this time during the small reverse flow. Finally, the cleaning is stopped and after pausing to allow

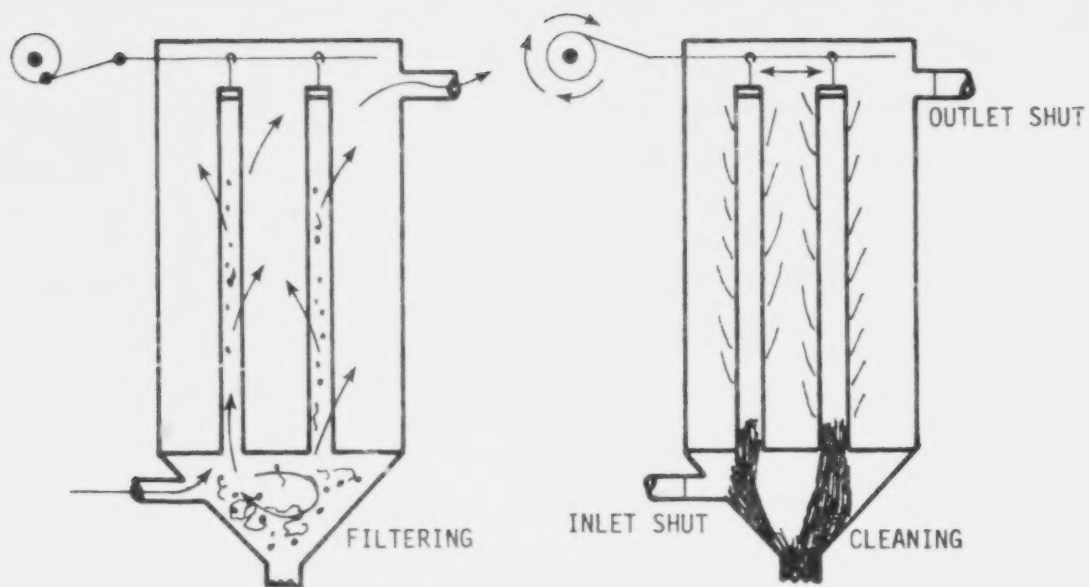


Figure 2-17. Diagram showing normal operation and shake cleaning of a fabric filter⁴¹.

the dust to settle, the inlet and outlet dampers are opened and the compartment begins its filtering again. The entire cleaning cycle may take from 30 seconds to a few minutes. Some installations do not return the compartment on line until the next one is ready to be cleaned, thereby achieving a fairly steady overall flow through the baghouse system at the expense of some over-capacity.

Reverse Flow: If the dust releases fairly easily from the fabric, a low-pressure reversal of the flow may be enough to loosen the cake without mechanical agitation. To minimize flexural attrition of the fabric, it is supported by a metal grid, mesh, or rings and is usually kept under some tension. The support is usually on the clean side of the tube or bag, although dirty-side support can help to keep the sides of the bag or the panels sufficiently apart to allow the cake to fall to the hopper.

There are several ways of accomplishing flow reversal. In addition to the standard dampers on each compartment, each one can have its own reversing fan. A few models have a traveling apparatus that goes from bag to bag or from panel to panel, blocking off the primary flow and introducing some air in the reverse direction with a secondary blower. Perhaps a simpler method is to take advantage of a suction on the dirty side or a relative pressure on the

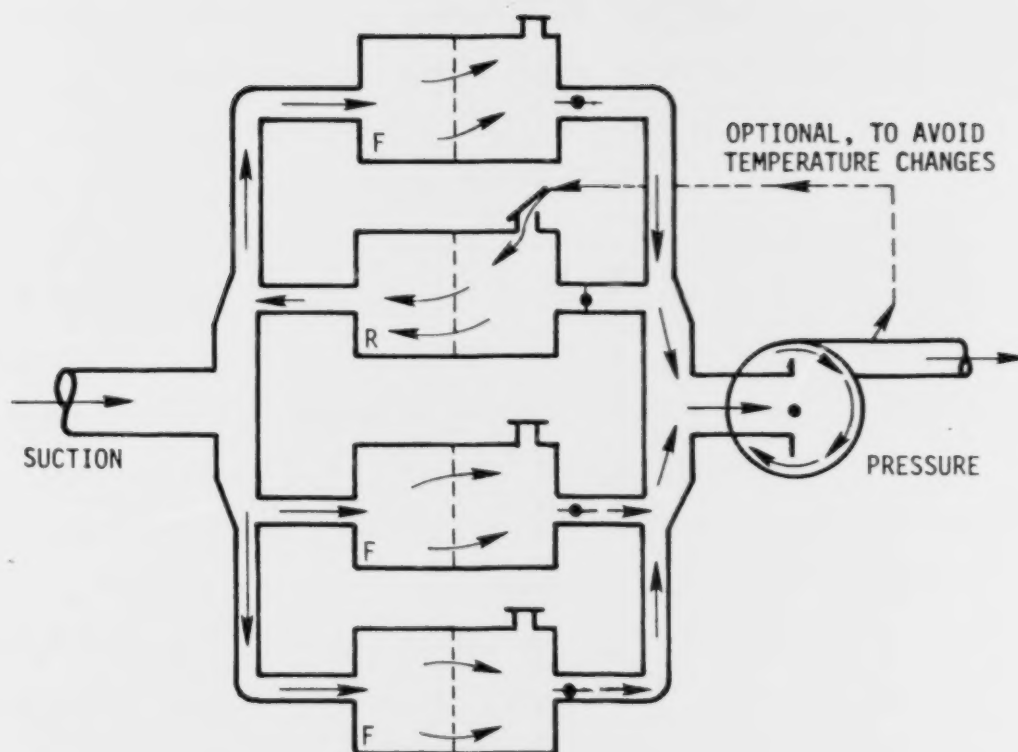
clean side, without using another blower as shown in Figure 2-18.

Any flow volume reversed through the filter must be refiltered. This means that in addition to taking cloth out of the system for cleaning, this cleaning method increases the total air flow in the remainder of the system. The net increase in air/cloth ratio is normally 10 percent or less.

Plenum Pulse: This method attempts to overcome some of the difficulties associated with other methods of cleaning. In this kind of equipment a sharp pulse of compressed air is released in the plenum chamber giving rise to some combination of shock, fabric deformation and flow reversal. The result is the removal of the dust deposit without more than a brief interruption of the filtering flow. The fabric receives a minimum of flexural wear, and the filter installation is smaller because the fabric is in use practically all the time.

The main distinction of pulsed equipment is the brief cleaning time, typically around one-tenth of a second. The very low ratio of cleaning time to filtering time makes pulsed equipment uniquely useful at high dust loadings.

Pulse Jet: This cleaning method is essentially similar to plenum pulse cleaning. The difference is that in pulse jet cleaning each bag is individually pulsed whereas in plenum



F: COMPARTMENTS FILTERING
 R: COMPARTMENT BEING CLEANED BY DAMPERED
 CONTROL FROM SUCTION SIDE OF SYSTEM

Figure 2-18. Schematic for Reverse Flow Cleaning
 During Continuous Filter Operation.⁴¹

pulse cleaning the whole compartment of bags is pulsed via introduction of pulsing air in the plenum chamber.

Vibration or Rapping: This method of cleaning is particularly successful with deposits that adhere relatively loosely to the bags. The vibration or rapping causes stresses at the fabric-cake interface which, in turn, release the dust cake from the fabric.

Sonic Assist: Agitation frequencies still higher than those used in vibration or rapping have been attempted with ultrasonic and sonic cleaning methods. Although these frequencies are known to slightly improve the preagglomeration of a few fine dusts, they have not, on the whole, been very effective in fabric cleaning.

All respondents in the ferroalloy industry use reverse air as the cleaning mechanism; 85 percent of the baghouses on electric arc steel furnaces use reverse air, while 15 percent use shakers; 50 percent of the baghouses on sintering strands use reverse air, 25 percent use shakers, while 25 percent use a combination of reverse air with a shaker assist.

2.6.4 Frequency of Cleaning

The cleaning cycle should be as short as possible so that no sizable portion of the total fabric will be out of service at any given time. With shake cleaning equipment,

for example, a common cleaning-to-deposition time ratio is 0.1 or less.⁴⁰ With a ratio of 0.1, 10 percent of the compartments in the baghouse are out of service at all times during operation. Therefore, the frequency of cleaning should be designed to minimize this ratio. As mentioned previously, with pulsing equipment, the cleaning time is very brief, thus a very low ratio of cleaning time to filtering time.

2.6.5 Selection of Fabric

Selection of fabric is generally based on the operating temperature and on the resistance of the fabric to abrasion and corrosiveness of the gases. Table 2-16 shows typical characteristics of various fabrics, which include cotton, wool, fiberglass, and other man-made fibers.³⁹ Many fabric weaves are available; or the fabric may be felted, a process whereby the identity of the separate yarns tends to be replaced by a more uniform mat. Felted fabrics are almost always cleaned by reverse jet or pulse-jet methods. Fabric characteristics may also be altered by further treatment for specific purposes, such as to decrease adhesion or improve wearability. Silicones are often used on fiberglass to reduce abrasion.

All of the baghouses identified in the questionnaire survey use polyester, nylon, or fiberglass bags. At

Table 2-16. CHARACTERISTICS OF VARIOUS FABRICS³⁹

Fiber	Operating Exposure, °F		Sup- ports Combus- tion	Air Permea- bility ^a , ² ft ³ /min/ft ²	Composition	Abra- sion ^b	Mineral Acids ^b	Organic Acids ^b	Alkali ^b	Cost ^c Rank
	Long	Short								
Cotton	180	225	Yes	10-20	Cellulose	G	P	G	G	1
Wool	200	250	No	20-60	Protein	G	F	F	P	7
Nylon ^d	200	250	Yes	15-30	Polyamide	E	P	F	G	2
Orlon ^d	240	275	Yes	20-45	Polyacrylonitrile	G	G	G	F	3
Dacron ^d	275	325	Yes	10-60	Polyester	E	G	G	G	4
Polypropylene	200	250	Yes	7-30	Olefin	E	E	E	E	6
Nomex [®] d	425	500	No	25-54	Polyamide	E	F	E	G	8
Fiberglass	550	600	Yes	10-70	Glass	P-F	E	E	P	5
Teflon [®] d	450	500	No	15-65	Polyfluoroethylene	F	E	E	E	9

^a ft³/min per ft² at 0.5 in. w.g.

^b p = poor, F = fair, G = good, E = excellent.

^c Cost rank, 1 = lowest cost, 9 = highest cost.

^d DuPont registered trademark.

temperatures above 400°F, the exclusive choice is fiberglass, whereas below 275°F polyester is preferred.

2.6.6 Degree of Sectionalization

Design of fabric filter sectionalization (the number of separate filter compartments) requires knowledge of the variation in gas flow with respect to process or plant ventilation, the sizes of commercially available units, and the expected frequency of maintenance.⁴⁰ Individual compartments in small collectors may contain as little as 100 ft² of fabric surface, although some large units with a capacity of 50,000 ft³/min may have only one compartment.⁴⁰ The largest collector to date is under construction in the electric utility industry and has a capacity of 4.5×10^6 acfm. With the exception of reverse jet and pulse jet units, it should be noted that at least one compartment in any collector will be out of service during the cleaning cycle.

2.6.7 Filter Housing

Configuration of the filter housing depends on the required fabric surface area and on the temperature, moisture content, and corrosiveness of the gases. When the baghouse is designed so that the dirty gas enters the inside of the bags under positive pressure, housing may be needed only for weather protection or for emission measurements.

The floor area required for baghouses depends on the filtering surface area, size of the bags, and spacing between bags. For example, 1750 ft² of filtering area can be provided in about 80 ft² of floor area by using bags 6 in. in diameter, 10 ft long, and allowing 4 in. between bags. If 12 in.-diameter bags are used, they must be about 14 ft long to provide the same filtering area in the same floor space, though 12 in.-diameter bags can easily be obtained in lengths of 20 ft or more when there is adequate head room. This configuration (12 in. x 20 ft) would provide a baghouse having about 2500 ft² of filtering area in the same floor space (80 ft²).⁴¹ The length/diameter ratio affects the stability of vertical bags, so care must be taken to ensure that bags do not rub together during operation or cleaning. The length/diameter ratio ranges from 5 to 40,³⁹ but more commonly varies between 10 and 25. Respondents in this study indicated a narrow range of 30 to 33 for the length/diameter ratio.

Design consideration must be given to allow adequate space for the collecting hopper below the filter bags. Hoppers are commonly designed with 45-degree or 60-degree sloping sides to provide adequate sliding, and with some dusts a 70-degree slope is required. Dust collected in the hopper can be removed by screw conveyors, rotary valves, trip gates, air slides, and other methods.

The most common construction material for the housing is steel; other materials, such as concrete and aluminum, are also used. Corrugated asbestos cement paneling is often used for the exterior roofing and siding of the housing in combination with interior walls and partitions of steel.⁴¹

2.6.8 Gas Conditioning or Cooling

The gases to be cleaned are frequently too hot to go to the baghouse immediately, so they are cooled before entering the filtration system. Use of a fabric filter on a sintering process generally does not require gas cooling. In the ferroalloy branch, however, electric arc furnace fumes are usually cooled by radiation or forced convection; whereas electric arc furnace fumes in the steel industry are cooled only if there is direct evacuation of the gases.

Three methods which can be used for cooling the hot gases are radiation and convective cooling, addition of outside air, and spray cooling with water.

Radiation and convective cooling do not dilute the gas and do not raise the dew point, but require large and costly equipment. To cool 100,000 ft³/min of air from 600° to 300°F would require a surface area of 100,000 ft² if the heat transfer rate for the cooler were 1 Btu/h ft²°F.⁴¹ Addition of outside air is simple, but it increases the gas volume to be handled, thus requiring more filter area and

energy consumption. Spraying can provide the greatest amount of cooling at the lowest total cost but its main disadvantage is that it increases the gas dewpoint. this can result in wetted bags and/or increased bag wear due to higher gas corrosiveness.⁴¹ Table 2-17 cites the advantages and disadvantages of different methods of temperature conditioning.

2.6.9 Correlations

As stated in Section 2.6 it is difficult to establish correlations between fabric filter design parameters and specific processes such as those discussed in this study. This is because of the similarities in the design of fabric filters from application to application. Thus only capital and annual costs are presented for fabric filters.

2.6.9.1 Capital and Annual Costs For Fabric Filters -

Typical installed costs and operating costs for fabric filters in the iron and steel industry are given in Figures 2-19 and 2-20 respectively. Although several respondents to the survey furnished cost figures, it was impossible to display these figures in a meaningful way. This arose from the divergent accounting methods used. Some respondents reported costs in terms of product produced, while others reported annual dollars, both with and without overhead absorption.

Table 2-17

METHODS OF TEMPERATURE CONDITIONING⁴¹

Radiation-Convection Cooling (long, uninsulated inlet ducts)

Advantages: Lowest flow volume of the three methods.
Smoothing or damping of flow, temperature, pressure or other surges, or peaks in the process effluent stream.
Saving of heat (building space heating).

Disadvantages: Cost of extensive ducting.
Space requirements of ducting.
Possibility of duct plugging by sedimentation.

Evaporation (by water injection well ahead of the filter)

Advantages: Low installation cost, even with automatic controls.
Capability of close and rapid control of temperature.
Capability of partial dust removal and/or gas control by scrubbing.

Disadvantages: Danger of incomplete evaporation and consequent wetting of the filter or chemical attack of the fabric or filter.
Increased danger of exceeding the dew-point and increased possibility of chemical attack.
Increased steam plume visibility, a hazard near highways.
Possible increase in volume filtered.

Dilution (by adding ambient air to the process effluent stream)

Advantages: Lowest installation cost, especially at very high initial temperatures.

Disadvantages: Substantial increase in total filtering volume.
Automatic control of both temperature and filtering velocity is not possible.
Uncontrollable intake of ambient moisture, dust, etc., without prior conditioning of the dilution air.

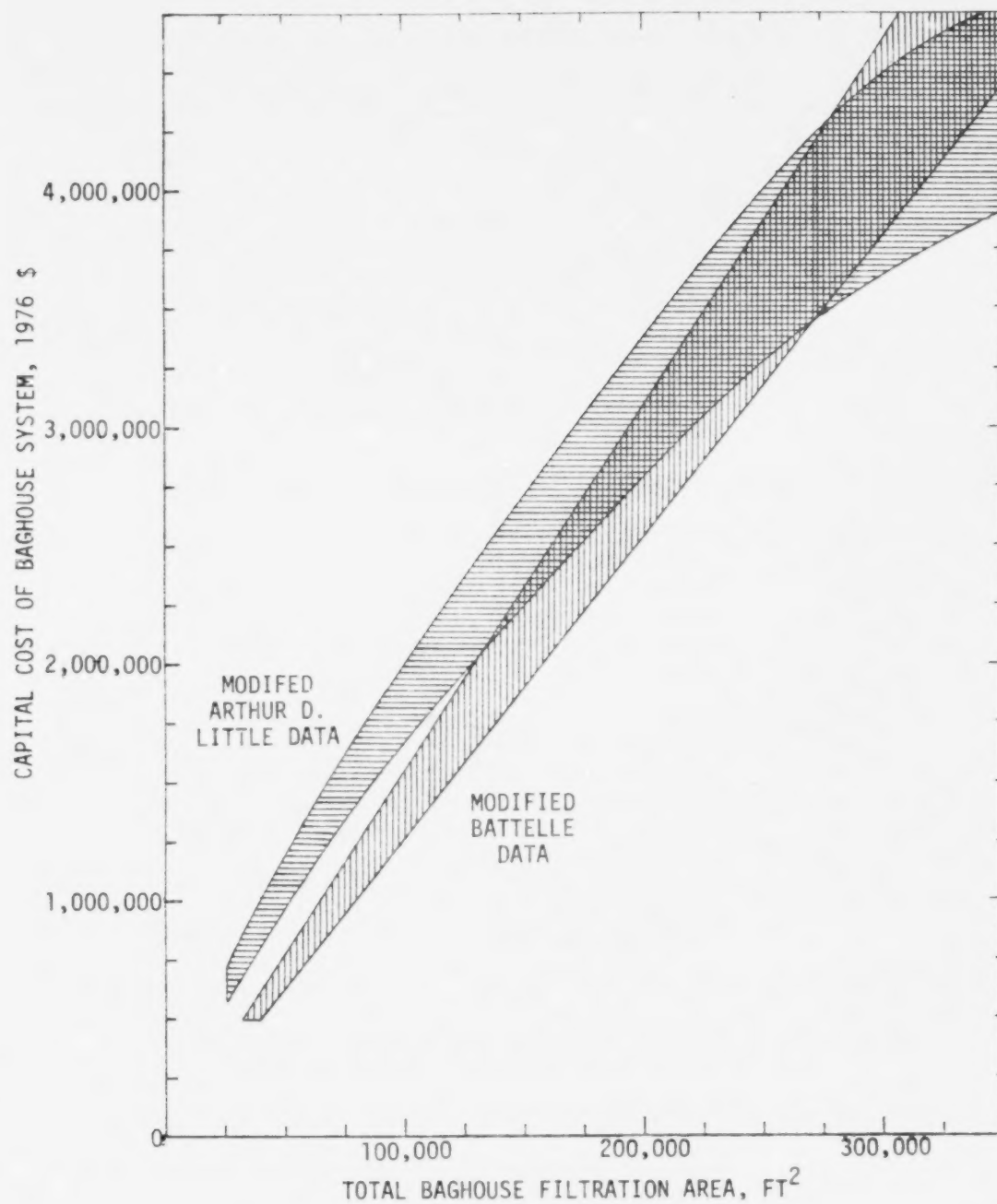


Figure 2-19. Installed cost of fabric filter systems.

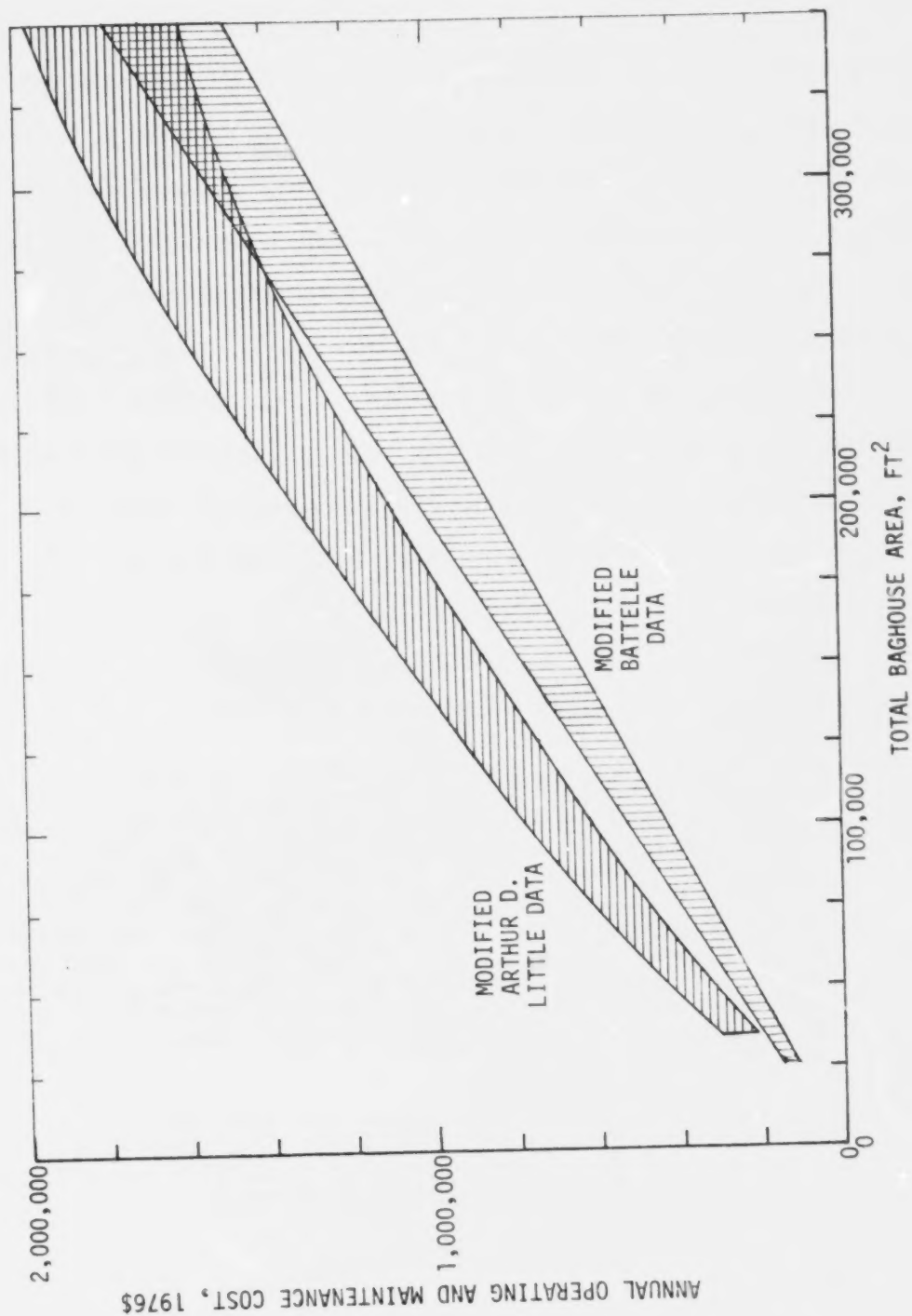


Figure 2-20. Annual operating and maintenance cost of fabric filter systems.

Figures 2-19 and 2-20 were derived by Midwest Research Institute from the 1969 Battelle study of the integrated iron and steel industry⁴ and from the 1975 Arthur D. Little study of the steel industry.⁴² A word of explanation is in order. In the original Battelle study, costs were related to volumetric flow rates for various applications. Here costs are related to the filtration area in order to eliminate effects of differences in air-to-cloth ratios. To illustrate this effect, consider that a baghouse of 100,000 ft² filtration area can clean 300,000 acfm of canopy air from an electric arc furnace shop, but only 150,000 acfm of gas from a sintering strand wind box.

Cost figures from the original Battelle report were updated according to the following:

1. Material cost was assumed to be 10 percent textile, 90 percent nontextile. The nontextile cost portion was assumed to be 35 percent labor and 65 percent iron and steel. Textile costs were escalated by the ratio of indexes from 1969 to 1976 for "man-made fiber textile products" from the U.S. Department of Labor.⁴³ Iron and steel prices were inflated by the ratio of indexes for "iron and steel" from the same source. Labor was escalated by using the ratio of "average weekly earnings for manufacturing nonsupervisory workers" from 1969 to 1976, as published by the U.S. Department of Labor.⁴⁴

2. Job site construction labor was escalated by the ratio of "average weekly earnings of contract construction nonsupervisory workers" from 1969 to 1976, as published by the U.S. Department of Labor.⁴⁴

3. Engineering charges were escalated by the ratio of "engineers' salary" from 1969 to 1976, as reported by the U.S Department of Labor.⁴⁵

4. Electrical power charges were inflated by the ratio of "average industrial charge for electrical power for users of 200,000 kWh/yr and above" from 1969 to 1976, as published by the Federal Power Commission.⁴⁶

5. Operating and maintenance labor was inflated by the ratio of "average weekly earnings for manufacturing nonsupervisory workers" from 1969 to 1976, as published by the U.S. Department of Labor.

6. Depreciation was charged to operation and maintenance based on a 10-year straight-line amortization of the total installed costs.

7. Capital charges were applied to operation and maintenance at 10 percent/yr of the total installed cost.

In 1973 the American Iron and Steel Institute authorized Arthur D. Little, Inc., (ADL) to undertake a study of the cost impact on the iron and steel industry of complying with existing and proposed air emission and water effluent regulations of the EPA.⁴² As part of this study ADL generated the following algorithms:

Equation 1 $I = 179.8Q^{1.76}$ where:

I = total installed cost of high complexity fabric filter system, 1972 \$

Q = gas volume, scfm

Equation 2* $OC = Q [22.27x + 0.072y + 0.15] + 0.05I$
where:

OC = annual operating cost, \$

* Equation 2 is condensed from the original which was designed to accommodate a variety of control devices.

x = power cost, \$/kWh

y = labor rate, \$/man-h

I = total installed cost, \$

Because these algorithms are insensitive to actual gas volume flow rate and air-to-cloth ratio (both of which are fundamental in the design of a real system), and because Equation 1 generates 1972 costs, the above algorithms have been modified according to the following considerations:

1. Fabric filters operate at 275°F, the maximum temperature of most common synthetic fabrics (i.e., no cooling is involved; therefore, no cooling cost penalty).
2. Fabric filters operate at a 2.5:1 air-to-cloth ratio.
3. Depreciation has been deleted from capital cost and charged to operation and maintenance on a 10-year straight line basis.
4. Capital charges have been deleted from capital investment and charged to operation and maintenance at 10 percent/yr.
5. Power cost is \$0.037/kWh.
6. Direct labor is \$4.98/man h.
7. General cost inflation compounded from 1972 to 1976 is 6 percent/yr.

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3.0 OPERATION AND MAINTENANCE AND COMMON MALFUNCTIONS OF PARTICULATE CONTROL DEVICES ON IRON, STEEL, AND FERROALLOY APPLICATIONS

As with other complex equipment, the successful functioning of pollution control systems depends not only on sound design and proper installation, but also on proper operation. Ideally, plant personnel who use and maintain the equipment should understand the engineering principles on which the system is based and apply this knowledge both in routine operation and maintenance and in emergency situations.

3.1 OPERATION AND MAINTENANCE OF ELECTROSTATIC PRECIPITATORS

Problems with electrostatic precipitators can arise when the equipment is brought on line and also after extended operation. Since the possible causes of poor performance are diverse, it is impractical to outline a single procedure for determining the nature of a specific problem. When a malfunction occurs, the operator must depend on his theoretical understanding of the equipment, backed by his practical experience. This section and related appendices, therefore, provide background information on precipitator

operation, together with detailed maintenance and troubleshooting procedures for the major component categories. Since the basic precipitator function is that of charging and collection of particles, the components and controls associated with the transformer-rectifier sets, rappers, and vibrators constitute the heart of the system.

The procedures presented in this report have been abstracted from Research Cottrell manuals. Although other manufacturers might recommend different procedures as dictated by details of system design, most of the major components and therefore the operating procedures are similar. Where possible, the recommended practices are interpreted in terms of their effect on equipment performance.

3.1.1 Background on Precipitator Operation

Electrostatic precipitation requires two groups of equipment: (1) the precipitation chamber, in which the suspended particles are electrified and removed from the gas, and (2) the high-voltage transformer and rectifier, which function to create the strong electrical field in the chamber.

The chamber consists of an outside shell (precipitator shell) made of metal, tile, or other material. Suspended within the shell are grounded steel plates (collecting electrodes) connected to the grounded steel framework of the

supporting structure and to an earth-driven ground. Suspended between the plates are metal rods or wires (discharge electrodes) insulated from the ground. They are negatively charged at voltages ranging from 70,000 to 105,000 V. The great voltage difference between the wires and the collecting plates sets up a powerful electric field, which imparts a negative charge to the solid particles suspended in the gas stream. Understanding this phenomenon requires some knowledge of electricity and chemistry; for practical purposes it is enough to know that the particles become electrostatically charged. The negatively charged particles are attracted to the collecting plates, which are at ground potential. The particles cling to the collecting plate and become electrically inert. Removal of the collected dust is best achieved by rapping the plates at an intensity and frequency that causes the dust to fall from the plates in sheets into a receiving hopper. Rapping that is too intense or too frequent will clean the collection plate, but it may also cause reentrainment of the collected dust into the gas stream.

Gas that enters the precipitator laden with particles is channeled through the precipitator outlet, while the dust collected in the hopper is removed by a dust handling system.

Figure 3-1 illustrates the major components of an electrostatic precipitator with top housing (as opposed to insulator compartments, which are used primarily for higher temperature precipitator applications). Appendix C-1 contains a more detailed explanation of precipitator operations, including subsystems and components such as transformer-rectifiers, rappers, vibrators, the upper precipitator, discharge wires, collecting plates, and the lower precipitator. The next section describes the fundamental operational procedures necessary for routine usage.

3.1.2 Precipitator Start-up and Shutdown Procedures

Operation of an electrostatic precipitator involves dangerously high voltage. Although all practical safety measures are incorporated into the equipment, extreme caution should be exercised at all times. An electrostatic precipitator is, in effect, a large capacitor which, when deenergized, can retain dangerous electric charges. Grounding mechanisms provided at each access point should therefore be used before entering the precipitator.

3.1.2.1 Preoperational Checklist - Before placing the equipment in operation, plant personnel should perform a thorough check and visually inspect the system components in accordance with the manufacturer's recommendations. A complete checklist of items is presented in Appendix C-2.

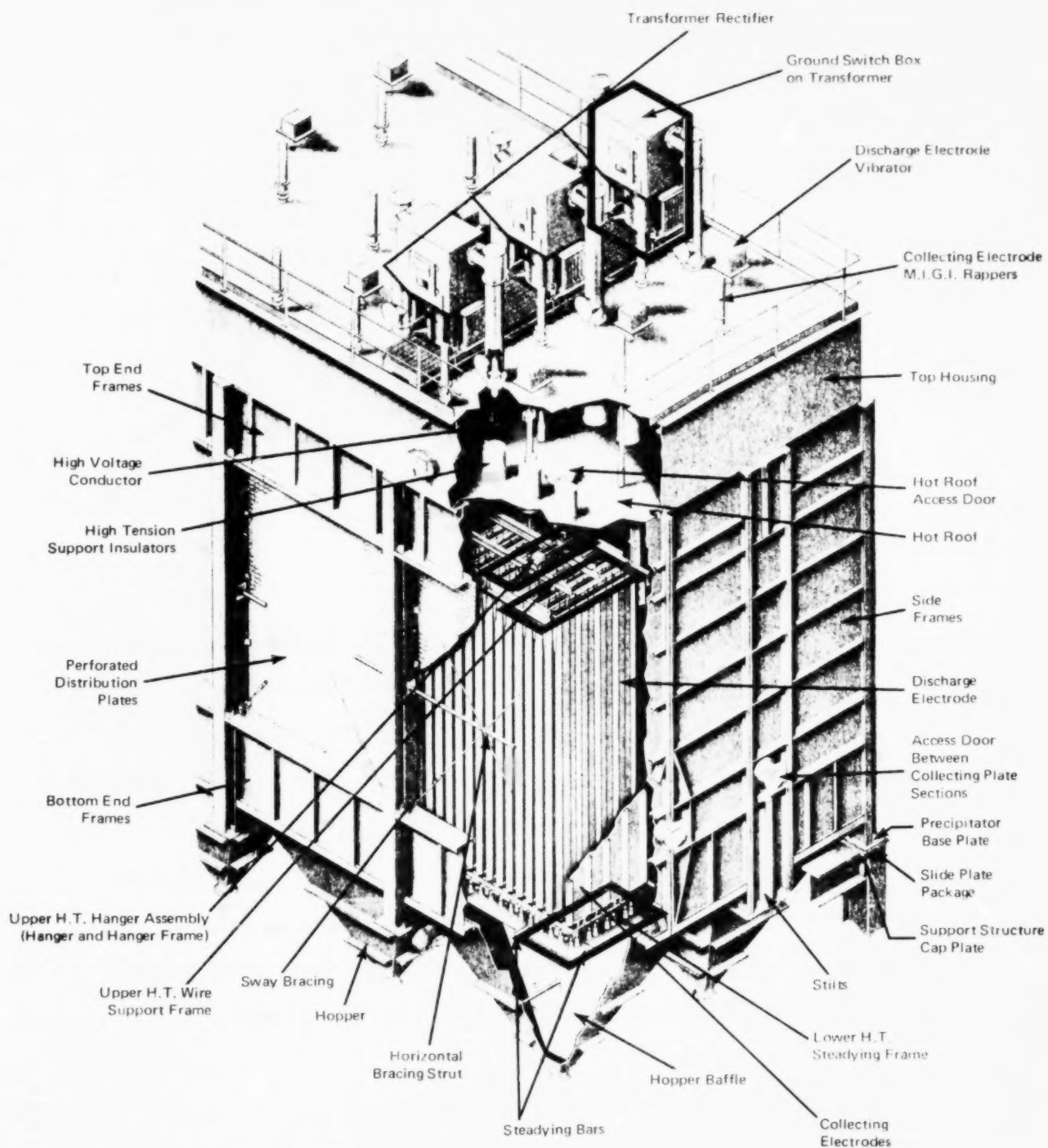


Figure 3-1. Typical electrostatic precipitator with top housing.

Some of the major items that should be checked are summarized below:

Control unit

Proper connections to control

Silicon rectifier unit

Rectifier-transformer insulating liquid level
Rectifier ground switch operation
Rectifier high-voltage connections made
High-voltage bus transfer switch operation

High-tension connections

High-tension bus duct
Proper installation
Vent ports properly installed

Equipment grounding

Precipitator grounded
Transformer grounded
Rectifier controls grounded
High-tension guard grounded
Conduits grounded
Rapper and vibrator ground jumpers in place

3.1.2.2 Air Load Tests - After the precipitator is inspected (i.e., preoperational check adjustment of the rectifier control, and check of safety features) the air load test is performed. Air load is defined as energization of the precipitator with minimum flow of air (stack draft) through the precipitator. Before introduction of an air load or gas load (i.e., entrance of dust-laden gas into the precipitator), the following components should be energized:

Collecting plate rappers
Perforated distribution plate rappers
High-tension discharge electrode vibrators
Bushing heaters, housing/compartments
Hopper heaters, vibrators, level indicators
Transformer rectifier
Rectifier control units
Ventilation and forced-draft fans
Dust-conveying system

The purpose of the air load test is to establish reference readings for future operations, to check operation of electrical equipment, and to detect any improper wire clearances or grounds not discovered during preoperation inspection. Air load data are taken with the internal metal surfaces clean. The data consist of current-voltage characteristics at intervals of roughly 10 percent of the T-R milliamperage rating, gas flow rate, gas temperature, and relative humidity.

For an air load test the precipitator is energized on manual control. The electrical characteristics of a precipitator are such that no sparking should occur. If sparking does occur, an internal inspection must be made to determine the cause. Usually the cause is (1) close electrical clearances and/or (2) the presence of foreign matter, such as baling wire, that has been left inside the precipitator.

After the precipitator has been in operation for some time, it may be necessary to shut it down to perform inter-

nal inspections. This provides a good opportunity to take air load data for comparison with the original readings.

3.1.2.3 Gas Load Tests - The operation of a precipitator on gas load differs considerably from operation on air load with respect to voltage and current relationships. The air load test is characterized by high current and low voltage, whereas the converse is true in the case of the gas load test. The gas load effect governs operation of the precipitator and the final setting of the electrical equipment.

In general, optimum precipitator efficiencies are obtained when the d.c. voltage applied to the precipitator is just at the threshold of sparking. The spark rate at this point will be on the order of 50 to 150 sparks/min and may be controlled at this level with automatic control.

3.1.2.4 Shutdown Procedure - To shut down the precipitator, the operator opens the control circuit start/stop switch and then opens the main circuit breaker. Before entering the system, the operator should follow all recommended safety procedures. Proper grounding of all precipitator parts is important. The key interlock system prevents access to the interior of each transformer-rectifier ground switch enclosure until the individual set is deenergized and the ground connections are made. This system prevents access to the interior of the precipitator, including top housing or

insulator compartments, precipitator roof doors, side doors, and hopper doors, until the transformer-rectifiers of each precipitator are deenergized and ground connections are made. Purging the system with ambient air may also be necessary from the standpoint of the safety of plant personnel who must inspect the precipitator internally.

3.1.3 Inspection and Maintenance During Normal Operation

A section has been included in Appendix C-3 consisting of detailed directions for plant personnel who are assigned responsibility for inspection and maintenance of precipitator systems. These instructions, while abstracted from one manufacturer's operation and maintenance procedures, are representative of the level of inspection and maintenance required for successful precipitator operation with minimum down time. Although electrical portions of a precipitator system require very little maintenance, the items enumerated in Appendix C-3 should be attended regularly if the equipment is to give optimum service. It is considered good practice to assign one operator on each shift the task of checking and recording data on electrical equipment at the start of the shift.

The cycle of inspection and maintenance during normal operation includes the following system components:

- Transformer-rectifier sets and associated equipment
and controls
- Transformer enclosure

- Overhead half wave/full wave switchgear
- Pipe and guard
- Plate rappers
- Vibrators
- Top housing
- Insulator components
- Plate hanger anvil beam
- Upper high-tension frame
- Discharge wires
- Collecting plates
- Lower precipitator steadying frame
- Hoppers and conveyors
- Precipitator shell

3.1.4 Maintenance Schedule and Troubleshooting

A detailed list of maintenance procedures that should be performed on a daily, weekly, monthly, quarterly, semi-annual, and annual basis, is likewise presented in Appendix C-3 as an example of the level of effort typically required to maintain optimum operation. For example, the annual inspection covers the following conditions or subsystems:

- Unusual dust accumulation
- Discharge wires
- Alignment of plates and wires
- High-tension and plate rappers
- High-tension frame support bushing
- High-voltage electrical control cabinet
- Transformer-rectifier sets

Table C-3-1 in Appendix C-3 lists a number of troubleshooting measures recommended by precipitator manufacturers for determining the most probable cause of precipitator problems, and Table C-3-2 gives an example of the frequency of failure and time required to repair various components of a typical industrial ESP.

3.1.5 General Precipitator Malfunctions

Many precipitator components are subject to failure or malfunction, which can lead to increased emissions. Faulty design, installation, or operation of the precipitator can cause these malfunctions. The reduction in efficiency is variable and depends on the severity of the malfunction. Many malfunctions are interrelated, with one malfunction causing another. A brief discussion follows on common precipitator malfunctions and how they affect emissions.

The most common malfunctions associated with precipitators stem from broken discharge wires and plugged dust hoppers. Other problems result from failure of rappers or vibrators and suspension insulators.

3.1.5.1 Broken Discharge Wires - When a discharge electrode breaks, it usually causes an electrical short circuit between the high-tens discharge wire system and the grounded collection plate. This electrical short trips the circuit breaker, disabling a section of the precipitator. Electrical erosion, mechanical fatigue, and dust hopper buildup are three common causes of electrode wire failure, along with many others.

The impact of wire failures on precipitator availability and efficiency is a function not only of the frequency of failure, but also the degree of sectionalization and the

difficulty involved in removing failed wires during unit operation. Most precipitators do not have suitable isolation dampers to allow safe access to the interior while the process is in operation; thus, the unit must shut down for removal of these broken wires. Inadequate sectionalization causes a greater drop in efficiency, and a number of wire breaks in different sections may seriously impair the operation of the precipitator.

Design methods that can reduce wire failures include fabricating discharge electrodes of the proper materials and applying shrouds and rounded surfaces to reduce localized sparking.¹ Frequent inspection can help prevent failures through detection of problems such as inadequate rapping and ash hopper buildup before they cause wires to fail. Because of the great number of wires in a precipitator, some wire failure is to be expected, even with a good operation and maintenance program.

3.1.5.2 Collection Hoppers and Dust Removal - Inadequate dust removal is a major cause of precipitator malfunctions. Most problems associated with hoppers are related to proper flow of the dust. Improper adjustment of the hopper vibrators or failure of the conveyor system is usually the cause of the hoppers failing to empty. Low flue gas temperature, which permits moisture condensation, can also cause plugging

of the hopper. This results from carrying the process exit gas temperature too low or from excessive leakage of ambient air into the hopper.

Buildup of dust can cause short-circuiting of the precipitator. It can also cause excessive sparking, which erodes electrodes and sometimes pushes internal components out of position, causing misalignment that can drastically affect performance. Reentrainment of dust also increases emissions.

Since dust buildup can affect so many of the precipitator components, a proper inspection schedule of the dust removal system is an important factor in eliminating or minimizing many common precipitator malfunctions.

3.1.5.3 Rappers or Vibrators - Poor performance can result from rapping forces that are either too mild or too severe. Although some reentrainment always occurs, effective rapping minimizes the amount of material reentrained in the gas stream. Rapping that is too intense and frequent results in a clean plate, which causes the collected dust to become reentrained rather than falling in sheets into the hopper. Inadequate rapping of the discharge electrode results in a heavy dust buildup with localization on the corona, excessive sparking, impaired performance, and possible grounding of the high-voltage system.

The first step in dealing with problems related to rappers and vibrators is to determine the adequacy of the rapping acceleration. An accelerometer can be mounted on the plates for this purpose, and an optical dust-measuring instrument in the gas stream can also be used to adjust the rappers.

If discharge electrodes are kept as clean as possible with minimum reentrainment, rapping intensity is then limited only by the possibility of mechanical damage to the electrodes and support structure.

3.1.5.4 Insulator/Bushing Failure - Suspension insulators are used to support and isolate the high-voltage parts of precipitators. Inadequate pressurization of the top housing of the insulators can cause dust deposits and/or moisture condensation on the bushing, which may result in electrical breakdown. Fouling and cracking of insulators reduce the effective voltage levels and collector performance, but rarely decommission a bus section.

Corrective or preventive measures include inspection of ventilation fans for the top housing and availability of a spare fan for emergencies. Frequent cleaning and checking the fans for damage from vibration are also necessary to ensure trouble-free operation.

Table C-3-3 in Appendix C-3 lists common precipitator malfunctions, their causes, the effects on emissions, and the corrective action required.

3.1.6 Operation and Maintenance Problems Which are Specific to Iron, Steel, and Ferroalloy Precipitator Applications

The information presented in the preceding sections is typical of most precipitators. Table 3-1, however, illustrates the important differences between utility and iron, steel, and ferroalloy precipitators.

Corrosion is clearly one of the basic problems contributing to loss in efficiency. Corrosion attack causing loss of collection area will probably increase sparking at the end of the corroded plate, which temporarily collapses the field and degrades performance. In addition, loss of plate area can cause secondary flows (cross-flows between gas passages) which can result in particle reentrainment. Localized turbulence at the corroded surface can also adversely affect particle attachment and the quiescent zone of particle migration near the plate surface.

Anticipation of severe corrosion potential is required so that adequate protection can be provided for in the initial design. Also in this connection, all points of air in-leakage should be eliminated. Cracked hopper welds and missing bolts should be replaced. Bolts on hopper doors should be tight and all seals inspected.

Table 3-1. COMPARISON OF DESIGN AND OPERATIONAL PROBLEMS OF
UTILITY, IRON, STEEL, AND FERROALLOY ELECTROSTATIC PRECIPITATORS

Item	Utilities	Iron/Steel/Ferroalloy
Lubrication:		
Screw bearings	-	Yes
Corrosion from air inleakage	Mild	Severe
Corrosion environment	SO ₃ (Mild)	SO ₃ , Cl (can be of considerable severity)
Explosive environment	None (Rare)	CO, H ₂ , CH ₄
Purge air	Air	Spent gas, natural gas may be used (air cannot be used if explosive gas/O ₂ ratios are likely to be met)
Explosions from air inleakage	None (Rare)	Possible
* Precipitator material selection	Mild steel	Stainless steel; (special consideration must be given to minimize rate of corrosion, e.g., Cl attacks stainless steel)
Dust buildups	Normal rapping	These dusts can be very tenacious
Dust removal	Pyramidal hoppers, Vacuum discharge	Trough hoppers, with rotary or double- dump valves or pyramidal hoppers with screw conveyors
Insulation	Required to minimize temperature drop	Required to minimize cold spots and thus corrosion particularly in corners, roofs, and doors of hoppers

In some cases the discharge electrodes can be attacked by corrosion. Ferrules on wires, in particular, may show significant corrosion. This could be the result of a galvanic couple between the discharge electrode and the ferrule, halogenic attack on the ferrule (which could lead to stress corrosion), or acid attack on the ferrule. To remedy this, replacement wires for such an installation should have ferrules made of the same material as the discharge electrode (mild steel basic bright wire). This change will not eliminate corrosion of the discharge electrodes, but it will ensure that the rate of corrosion for the discharge wire and ferrule will be equal and probably slower.

Another problem area is high-voltage tracking on the insulators as a result of the formation of condensables in the insulator compartments of installations in areas with cold, damp, winter climates. In such cases, the pressure and temperature of the insulator compartment steam coil supply can be increased to prevent condensate formation. In addition, the purge lines might be steam-traced and re-insulated.

A 1974 survey by the TC-1 committee² seems to confirm the above observations. In a comparison of precipitator maintenance problems for various industries, respondents

from the metallurgical industry indicated that rappers/vibrators presented the largest maintenance problems, followed by insulators and discharge electrodes, collecting plates, and dust removal systems. Table 3-2 compares maintenance problems for utility and metallurgical precipitators.

3.2 WET PRECIPITATORS

3.2.1 Description

As discussed in Section 2.4, several types of wet precipitators are available. Basically, they can be categorized structurally as to whether they are the plate-type or pipe-type, the latter being used principally on scarfing operations, and also with regard to the method of water introduction. The pipe-type usually has a weir-overflow arrangement or a continuous spray with a downward vertical gas flow. Plate units have either a combination presaturation continuous spray or a spray with intermittent wash and horizontal or vertical gas flow. Figure 3-2 presents illustrations of the above three types of wet precipitators.

Realizing 1) that there are a number of different configurations which wet precipitators can have; 2) that there are a limited number of applications as compared to more conventional devices; and 3) that generalized operating and maintenance practices have not been disclosed in the

Table 3-2. COMPARISON OF MAJOR MAINTENANCE PROBLEMS FOR
UTILITY AND METALLURGICAL PRECIPITATORS^a

Industry	Discharge electrodes, %	Rapper/ vibrator, %	Collecting plates, %	Dust removal system, %	Insulators, %
Utilities ^b	35.2	5.7	13.6	31.8	1.1
Metallurgical ^c	25.0	33.3	22.2	19.4	25.0

^a Indicates users' opinion of which category the major problem area in his experience. (Reference 2)

^b Based on 63 utilities reporting on 88 precipitators.

^c Based on 22 metallurgical processes reported on 36 precipitators.

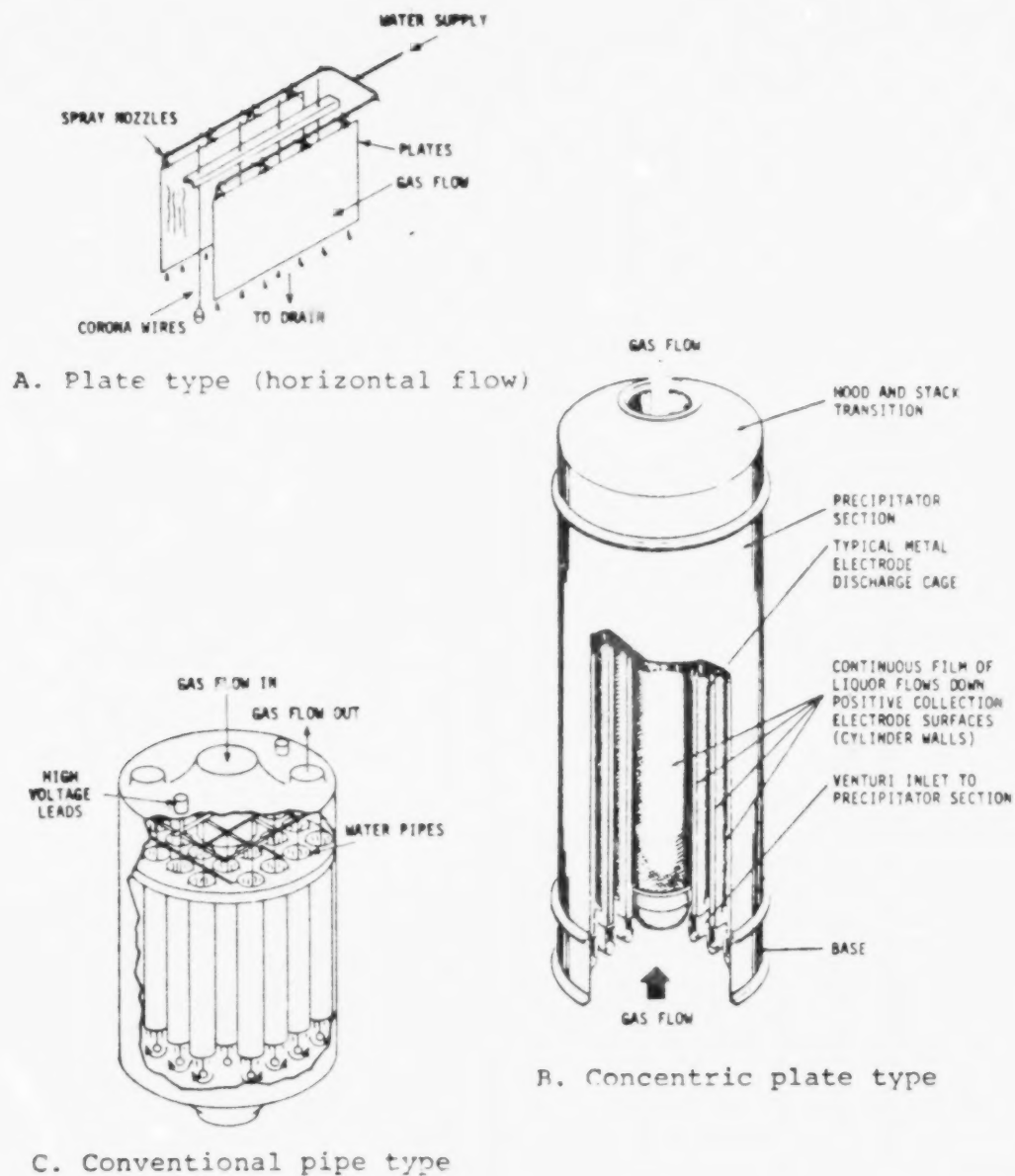


Figure 3-2. Three types of wet electrostatic precipitators.

literature; only typical points will be covered in this section.

Where components of a wet precipitator are similar to those of a dry precipitator, the operation and maintenance procedures outlined in Section 3.1 can be considered generally applicable.

3.2.1.1 Plate-type (horizontal flow) - The effluent gas stream is usually preconditioned to reduce temperature and achieve saturation. Upon entering the inlet nozzle, the gas velocity decreases due to the diverging cross section. At this point, additional sprays may be used to create good mixing of water, dust, and gas as well as ensuring complete saturation before the gas enters the electrostatic field. In addition, baffles are often used to achieve good velocity distribution across the inlet of the precipitator.

Within the charging section, water is sprayed in near the top of the plates in the form of finely divided drops. They become electrically charged and are attracted to the plate. In this manner, the plates obtain an even coating of water. Simultaneously, solid particles are charged and "migrate" and attach to the plates. Since the water film is moving downward by gravity on both the collecting and discharge electrodes, the particles are captured in the water film, which is disposed of from the bottom of the precipitator in the form of slurry.

3.2.1.2 Concentric-Plate-Type - This design, applied to scarfing applications, utilizes an integral tangential prescrubbing inlet chamber followed by a vertical wetted-wall concentric ring electrostatic precipitator chamber.^{3,4}

The concentric cylindrical collection electrodes are wetted by fluids dispensed at the top surface of the collection electrode system. The discharge electrodes consist of an expanded metal system with uniformly distributed corona points formed on the mesh background. This type of discharge electrode system is supposed to provide a combination of a high, nearly uniform electric field associated with a parallel plate system, and a nearly uniform corona current density distribution associated with the closely spaced corona points on the electrode system. Higher gas flows can be handled by the addition of more concentric electrode systems and by increasing the length of each electrode.

3.2.1.3 Conventional Pipe-Type⁵ - For scarfing applications the pipe-type configuration is preferred to the plate-type, since it appears to distribute water more adequately during the washing cycle. Weirs may also be used in some cases to ensure that the tubes are kept clean.

The actual system consists of a number of vertical collecting pipes. In the center of each is a discharge electrode (wire type), which is attached to the upper

framework and held taut by a cast iron weight at the bottom. The lower steadying frame keeps the weights and thereby the wires in position.

The upper frame is suspended from high voltage insulators housed in compartments on top of the precipitator shell (casing). Heating and ventilating systems help to prevent moisture and dust from accumulating in the insulator compartments.

The washing system usually consists of internal nozzles located at the top of the plates. At specified intervals (after approximately 20 blooms have been scarfed) the nozzles provide a thorough washing of the tubes. While the washing is taking place, the louver damper to the exhaust fan is closed to prevent droplet carry-over.

3.2.2 Operation

3.2.2.1 Preoperation - Before initiating the start-up procedure, all of the major items of equipment, connecting pipes, lines, and auxiliaries must be inspected, cleaned, and tested.

Checkout of the following items is suggested following the recommendations of the manufacturer:

Water Spray System --

Check for adequate flow, leaks, and pressures in all lines.

Check orientation of nozzles.

Inspect drain system.

Check all clearances between piping and high voltage (H.V.) system.

Precipitator Internals --

Inspect all H.V. system connections to transformer-rectifier (T-R) sets, bus ducts, and grid.

Insulators should be checked for cleanliness, cracks, and chips.

H.V. bus ducts to insulator connection should be tight.

Both heaters and pressurizing fan should be in proper operating condition.

Access doors and plates must have good seals and good interlock contact.

T-R Sets --

Check oil level, tight electrical connections, and proper operation of ground switch.

Control Panels --

All fuses and indicator lamps for all H.V. items, heaters, and blowers should be functioning.

3.2.2.2 Start-up

Heaters on.

Pressure blower energized.

H.V. circuit breaker on.

Activate spray system allowing sufficient time to clear air from lines.

Open damper to introduce effluent gases.

3.2.2.3 Shutdown

Inlet damper closed.

Deenergize precipitator.

Shut down spray system.

Heater and blower system should remain energized to prevent accumulation of moisture on the H.V. insulators.

3.2.2.4 Normal Operation

Heaters and blowers are energized normally.

Spray system always activated just prior to energizing the H.V. system.

Gas flow monitored by damper.

Water pH must be monitored at the waste discharge.

3.2.3 Inspection and Maintenance During Normal Operation

Actual inspection and maintenance practices are quite specific to the particular system used and the manufacturer's instructions should be closely followed. Since precipitators operate with very high voltage, precipitator internals must be properly grounded. Before anyone enters the precipitator, the gas flow must be turned off and the unit cooled to a safe temperature. Protective apparatus such as a respirator may be needed.

General inspection and maintenance practices are briefly outlined below.

3.2.3.1 Mechanical Maintenance - All internal components should be checked for alignment, excessive dust buildup, tight bolts, structurally sound welds, and general structural integrity of the cross bracing and other support members. Since the support insulators perform such a vital function in electrostatic precipitation, the structural support end of the H.V. insulator in the H.V. housing must be thoroughly inspected for cracks, chips, etc.

3.2.3.2 Water System - All pumps, internal spray nozzles, and related valving and piping should be checked. Nozzles are subject to plugging and therefore should be routinely disassembled, cleaned, and/or replaced as necessary. Main water pressure supply pumps and all pipe joints must be checked for leaks and all couplings for tightness. Nozzle orientation should be checked to ensure that the intended spray pattern is being achieved.

3.2.3.3 Electrical System General areas to check include the H.V. control panel, the heater and blower control panel, H.V. insulators, heater system thermostats, T-R sets, and all related electrical connections. Where wet precipitator systems contain items similar to dry precipitators, many of the inspection and maintenance practices outlined in Appendix C-2 will apply.

3.2.3.4 Schedule - The items outlined for maintenance with their corresponding intervals appear in Table 3-3 by permission of MikroPul.

3.2.4 Characteristic Maintenance Problems of Wet ESP's

Pilot tests of the wet ESP on Bethlehem Steel's Lackawanna, New York, plant showed that while using recirculated acidic water, the potential for corrosion of such reasonably priced alloys, such as 316L stainless was great.⁴ Operating in a pH controlled mode, however, of greater than 7.0, resulted in buildup of calcium and magnesium carbonate scale on spray nozzles and other critical components of the wet ESP, rendering it inoperable. Water distributor plugging and solids deposition resulting from the recirculation of the acidic solids-laden liquor were also encountered, with pilot testing of a second brand of wet ESP.

During full-scale testing, however, it was found that with regular weekly maintenance which included a general cleaning and inspection, the wet ESP performed very successfully. It was noted that regular attention to the recirculated water system was necessary to maintain the strict water quality requirements necessary for successful wet ESP operation.⁴

Table 3-3. SUGGESTED MAINTENANCE SCHEDULE FOR WET PRECIPITATORS

Component	Interval	Maintenance procedure
Key interlocks	Yearly Yearly Yearly	a. Check for corrosion and clean. b. Check that key fits and turns easily. Lubricate as required. c. Check proper positioning of dust caps.
Ducts and dampers	Quarterly Quarterly	a. Open and close dampers. Operation must be smooth and positive. b. Check ducts for an accumulation of dust. Clean as necessary.
Precipitator	Quarterly Quarterly	a. Check condition of paint and touch up as necessary. b. Clean corroded areas inside casing thoroughly.
Access doors	Quarterly Quarterly	a. Check seal for tightness. b. Inspect gaskets and replace if damaged.
Collecting plates and discharge electrodes	Quarterly Quarterly	a. Clean thoroughly. b. Check hanging fixtures for damage.
Baffles	Quarterly	a. Clean thoroughly.
Hopper	Quarterly Quarterly	a. Clean thoroughly. b. Check drain lines for clogging.
High voltage system: T-R set	Quarterly Yearly Yearly Yearly Yearly Yearly Yearly	a. Check oil level. Add oil if required. b. Check and tighten electrical connections. c. Replace damage wiring. d. Clean output bushing. e. Check output bushing for cracks or damage. f. Check continuity of ground wire. g. Check grounding switch for positive action.

(Continued)

Table 3-3. (Continued)

Component	Interval	Maintenance procedure
High voltage system:		
Insulators	Quarterly Quarterly Quarterly	a. Clean thoroughly and dry. b. Check for cracks or other damage. c. Tighten electrical connections.
Control panel	Quarterly Yearly Yearly Yearly Yearly	a. Check panel switches for positive action. b. Check and tighten electrical connections. c. Check condition of internal components. d. Clean inside and outside of panel. e. Check fuses for condition.
Heater & blower system: Heaters	Yearly Yearly Yearly	a. Check continuity of each shipment. b. Check and tighten electrical connections. c. Check clearance around insulator.
Blower	Weekly Yearly	a. Replace air filters. b. Check condition of blower and blower motors.
Control Panel	Yearly Yearly Yearly Yearly Yearly	a. Check panel switch for positive action. b. Check and tighten electrical connections. c. Check condition of internal components. d. Clean inside and outside of panel. e. Check condition of fuses.
Spray system	Weekly Weekly	a. Check pressure at nozzle head. b. Check spray pattern.
Operating checks	Daily Daily Daily	a. Check pH of water system. b. Visually check indicators for burned-out lamps. c. Check input and output meters for correct readings.
Dampers	Monthly	a. Lubricate operators.

3.3 WET SCRUBBERS

3.3.1 Description

Devices of this type use a moving gas stream to atomize liquid into drops and then accelerate the drops. Acceleration of the gas provides impaction forces as well as intimate contact with the liquid stream. The typical gas-atomized spray devices are the venturi scrubber and the flooded disc scrubber. In the venturi scrubber liquid is introduced at the throat; whereas, in the flooded disc scrubber liquid is introduced slightly upstream of the throat, flows over the edge of the disc, and is atomized.

Many differences in design and operation may be noted within this category with respect to the following: method of adjusting pressure drop (the difference being between the true venturi and the annular orifice); the method of water introduction (viz. sprayed in or cascaded in); and the method of moisture elimination (viz. centrifugal moisture eliminator with spinning vanes or multacentrifugals). In any event, most gas atomized spray scrubbers use the converging and diverging section typical of the venturi throat.

A typical flooded disc scrubber system for particulate collection consists of a flooded disc scrubber, a mist eliminator with sump, two recirculation pumps, and one booster fan or I.D. fan. Sometimes a gas prequencher is required for treating high temperature gas.

The flooded disc scrubber shown in Figure 3-3 is composed of a disc in the tapered throat section of a vertical hollow cylinder. The disc is supported by a pipe and an open annulus is formed between the wall and the disc. Atomization takes place at the annulus as gas flows through it and scrubbing water is simultaneously ejected across the disc face. As a result, millions of fine water droplets are created and used for particle capture in the gas stream. The particulate collection efficiency of the scrubber depends on the degree of atomization, which in turn is indicated by the pressure drop across the scrubber. This pressure drop can be regulated by controlling the vertical displacement of the disc in the venturi throat section, either automatically or manually. The pressure drop for fine particulate collection must be higher than that for a coarse particulate if the same collection efficiency is required. When particle size is uniform, the pressure drop for a high collection efficiency has to be higher than that for a low collection efficiency.

The purpose of the mist eliminator is to separate dust-laden water droplets from the gas stream by centrifugal force. This water then flows by gravity to a sump for recirculation back to the scrubber. The recirculated slurry gradually increases in solids content, the level of which is

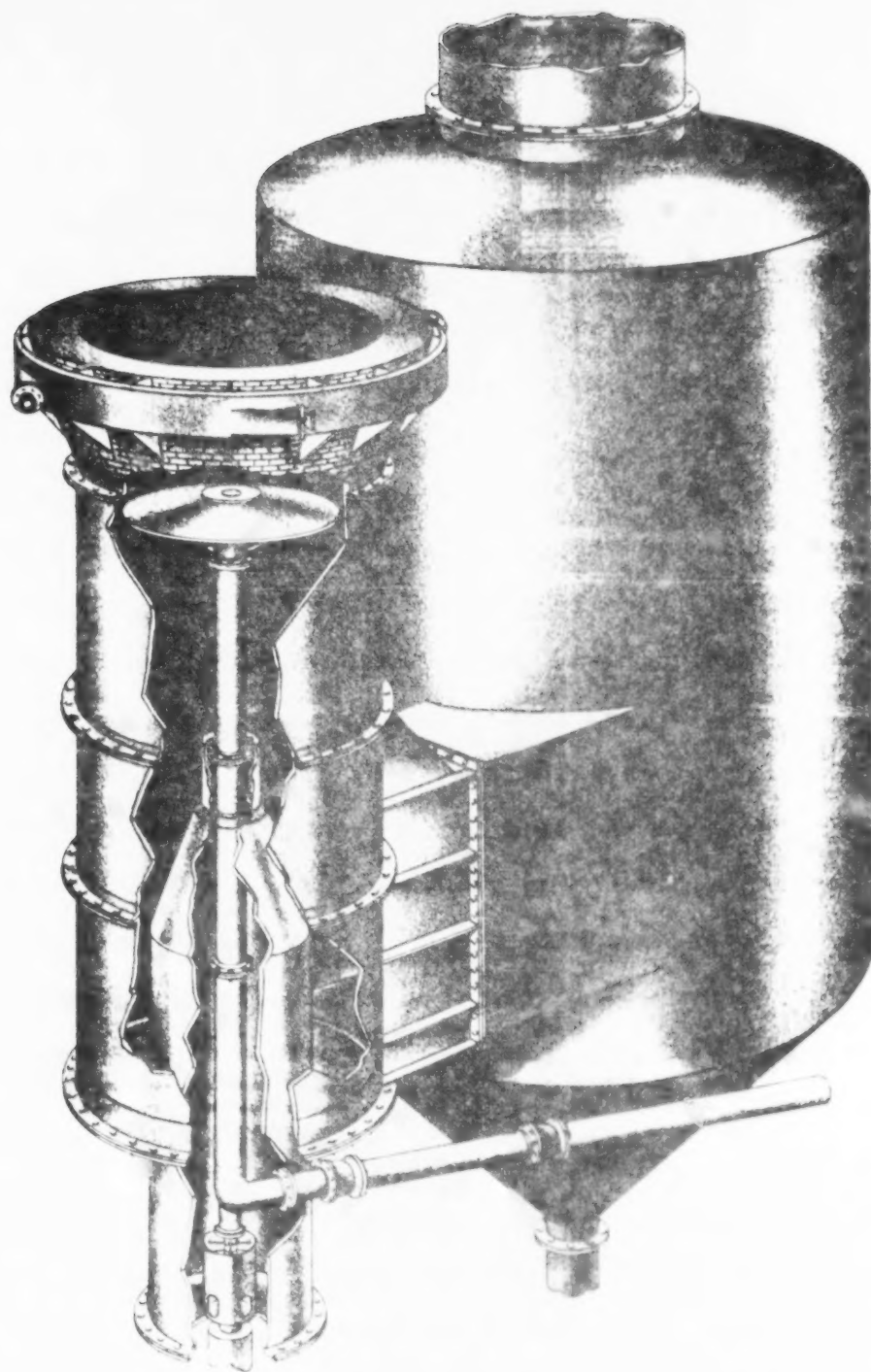


Figure 3-3. Research Cottrell Flooded Disc Scrubber.

monitored by a density control device equipped with an alarm. If the level of solids becomes too high, the slurry can be purged from the system through the discharge vent of the recycle pump. Water is lost from the sump during operation due to slurry purging and water vaporization, the latter resulting from the contact of hot gas with the scrubbing liquor. The amount of water lost is monitored by a slurry level control, and if need be a makeup stream is pumped to the recirculation sump.

All of the variables are controlled within the high and low limit. Any operation condition out of the control limit is indicated by an alarm which warns the operator. The major controls and alarms designed in the scrubber system monitor pressure drop across the scrubber, slurry density in the scrubber, slurry level of the recirculation sump, and slurry flow rate to the scrubber. For the purpose of safety, interlock circuits should be designed for the scrubber system to protect the equipment in the event of an emergency.

3.3.2 Operation

3.3.2.1 Preoperation - Before start-up, all major items of equipment, connecting pipes and auxiliaries must be inspected, cleaned, and tested. In newly installed systems, the first step should be an air test of fans and ductworks,

and a hydraulic test of pipings and valves to check for leaks and instabilities. A water test of the system should also be carried out to ensure that equipment, instruments, and control/safety systems are working properly. The items which should be checked during preoperational tests on a flooded disc venturi scrubber are summarized below:

° FD/ID Fan

Electrical controls

Fan bearing coolant system

Alignment

Lubrication

Vibration sensors

Bearing temperature sensors

° Pumps

Belt tension, pump rotation, pump alignment, lubrication, seal water, packing, pressure gauge, suction and discharge valves, motor bearing temperature, hydraulic system (for flooded disc control pump), etc.

° Control Systems

Flue gas bypass

Flooded disc pressure drop

Makeup water rate

Recirculation sump level

Slurry density

Slurry purge rate

- ° Safety System (interlocks and alarms)

High flue gas pressure

Low level in sump

High and low density

- ° Utilities

Electric power

Instrumentation air

Process water

Process return water

3.3.2.2 Start-up - To start a system for operation or for a water test, one must follow the procedure described in the designers' operating manual. Several steps for the start-up of a new venturi scrubber installation are outlined below:

1. Close all drain valves.
2. Turn on the circuit breakers for all instruments and electric valves.
3. Set all monitoring instruments to zero reading.
4. Start the service water system and raise the water level in the sump to the defined level.
5. Turn on the recycle pump circuit breaker, and start the operating and standby pumps.
6. Turn on the circuit breaker for the disc control pump, start the disc control pump, and adjust the high and low limits of the pressure drop indicator.
7. Close the flue gas bypass dampers and start the fan.

8. Check the scrubber pressure controller and the system monitoring instruments.

3.3.2.3 Shutdown - A general procedure for planned shutdown of a flooded disc scrubber system is outlined below.

1. Turn the flue gas damper to the bypass position and stop the fan.
2. Close the makeup water and slurry couple valves.
3. Stop the recycle pumps (both operating and stand-by).
4. Open the drain valves at the slurry pumping lines and flush the lines, gauges, and pumps with water.
5. Stop the disc control pump and leave the disc in the fully raised position.
6. Open the drain line on the pressure gauge to the throat and disc and allow the line to drain.

3.3.2.4 Normal Operation - Under normal operating conditions, all control variables should be operated in the defined ranges. These control variables include the scrubber pressure drop, recycle pump rate, makeup water rate, slurry density, slurry purge rate, and recirculation sump level.

An abnormal condition would be indicated by an alarm. If it cannot be corrected by the operator, under certain circumstances an interlock will open the flue gas bypass damper and shut down the scrubber system.

The alarm conditions involved in the system are outlined below:

(1) Scrubber pressure drop --

An alarm condition may occur owing to a malfunctioning pressure drop controller, failure of the disc control pump, a jammed disc, or a rapid change of the boiler load.

(2) Slurry density --

An alarm condition may occur because of a malfunctioning control, a defect in the density control valve, a malfunction in the sump level control, or a makeup water rate change.

(3) Recirculation sump level --

An alarm condition may be due to a malfunctioning control or excessive or insufficient slurry in the sump.

(4) Others --

An alarm condition may be caused by plugged lines, closed valves, pump trouble, or fan trouble.

3.3.3 Inspection and Maintenance During Normal Operation

Many items on the preoperation check list should be inspected during routine maintenance, which generally includes unplugging lines, nozzles, pumps, etc.; replacement of worn equipment parts, erosion/corrosion prevention liners, and instruments (level indicators, density indicators, etc.); and repairing damaged components (when practical from the standpoint of labor and materials).

Table 3-4 indicates the manpower requirements for maintenance involving scaling and plugging for both the wet approach and liquid injection venturi scrubbers.

Table 3-4. MAINTENANCE FOR PLUGGING AND SCALING

VENTURI SCRUBBER⁶

(From interview with P. Wechselblatt, Chemico)

Type of venturi scrubber	Type of problem			
	Plugging		Scaling	
	Mechanical cleaners	Cylinder cleaners	Chemical cleaning	Hand cleaning
Wet approach	1 man/shift/ mo	1 man/shift/ mo	3 men/shift/ wk	1 man/shift wk
Liquid injection	1 man/shift/ mo	1 man/shift/ mo	3 men/shift/ wk	1 man/shift/ wk

Table 3-5 lists maintenance requirements for two ranges of pressures, various lining materials, and gas characteristics. This table should be useful in the selection of scrubber liners for venturi units for the various iron and steel/ferroalloy applications.

The following check list is based on problems encountered in scrubber operation. These should be checked routinely and corrected according to the manufacturers' recommended procedures.

Check the scrubber disc to ensure even water distribution across its surface.

Check erosion and corrosion of all scrubber internal surfaces, especially corrosion underneath scale build-up. Repair as necessary.

Clean and descale all scrubber internal surfaces. While descaling, exercise care to prevent damage to the linings.

Table 3-5. SCRUBBER MAINTENANCE⁶
(From interview with P. Wechselblatt, Chemico)

Type of liner	Pressure drop							Gas characteristics			Comments
	>30" ΔP		<30" ΔP		Repair time	Corrosive	Abrasive				
	Life cycle, yrs	Repair time	Life cycle, yrs	Repair time							
Ceramic											
Silicon Carbide	3-4	2 men/wk	10	2 men/1 wk	Poor	Excellent	Good (midly corrosive)				
Cement	1	2 men/wk	4	2 men/1 wk	Poor	Poor	Good (midly corrosive)				
Rubber	1	2 men/2 wks	5	2 men/2 wks	Excellent	Good	Good				For cutting type particles for erosive but not sharp particles
Rubber	5	2 men/2 wks	10	2 men/2 wks	Excellent	Good	Good				
Plastic			Indefinite	1 d							Patchable lining
Steels											
Carbon	2-6	Patchable	6	Patchable	Poor	Fair	Fair				Good for chlorides
316	2-6	Patchable	6	Patchable	Excellent (arid)	Fair	Fair-good				Not good on chlorides
304	2-6	Patchable	6	Patchable	Good (arid)	Fair	Good				Except for SO ₃ and Cl ⁻
Inconel 625	2-6	Patchable	6	Patchable	Good	Good	Good				
Hastoloy	2-6	Patchable	6	Patchable	Excellent	Good	Good				

Check the disc operation and perform maintenance on the hydraulic packing.

Check the nozzles for buildup and/or damage. Repair or replacement may be necessary.

Check for solids buildup in blowdown lines. Cleaning may be effected without system shutdown and a flush connection may be installed to prevent this condition in the future.

Check for corrosion, erosion, and leaks in lines where protective liners may have deteriorated. Replace liners as required.

Check operation of mist eliminator. Formation of droplets can be caused by excessive gas flow rate, plugged drains from the moisture eliminator, or condensation in the outlet duct.

Check pumps for wear, seal water, packing, and smooth operation.

Check dampers and damper linkages for proper positioning and wear.

Fan check should include lubrication, fan bearing coolant, belt wear, and belt tension, and impeller erosion/corrosion.

Inspect all interior surfaces and condition of mist eliminator and sump during major outages.

Exterior inspection should include a check for leaks in all process and control lines, ductwork, and expansion joints.

Note the condition of all instruments, e.g., level probes and density probes with regard to solids buildup. It is impractical and usually impossible to remove solids buildup on the probes. In many cases the probes must be replaced.

Perform a final check for proper operation of density sensors, pressure drop control, and level elements.

Spare Parts - The minimum inventory is one of each part for each venturi scrubber. The inventory for a venturi system is given in Table 3-6.⁶

Manpower Requirements - The preceding discussion has given an indication of maintenance items, maintenance times, and spare parts inventory for a venturi scrubber system. Table 3-7 completes this picture by presenting the types of personnel generally required to perform maintenance on various parts of the venturi scrubber system.⁶

3.4 OPERATION AND MAINTENANCE OF FABRIC FILTERS

3.4.1 Background Information on Fabric Filter Operation

A baghouse consists of a large metal box divided into two chambers or plenums, one for dirty air and one for clean air. Rows of cloth bags form a partition or interface between the plenums. A polluted gas stream is ducted into the dirty air plenum, where it is distributed evenly to the bags. The gas passes through the bags, enters the clean air plenum, and is exhausted into that atmosphere through a stack. Greater than 99.9 percent of the particulate matter in the process effluent can be filtered out by the bags if the system is designed, operated, and maintained properly.

Upon start-up of a baghouse with new bags, some stack emissions are usually visible. This is because the bag fabric which is the filtering medium, is porous, and allows

Table 3-6. SPARE PARTS INVENTORY FOR VENTURI SCRUBBER⁶

(From interview with P. Wechselsblatt, Chemico)

Section of the system	Type of parts						
	Motors	Mist elimi- nator modules	Seals	Bearings	Impeller	Reamers (50% of total)	Packing material
Scrubber						X	X
Separator							
Fan	X		X	X	X		
Pump(s)	X		X	X	X		
Mist eliminator		X					
							Adjust- able throat- damper
							None

Table 3-7. TYPE OF MAINTENANCE REQUIRED - VENTURI SCRUBBER SYSTEMS⁶

(From interview with P. Wechselblatt, Chemico)

Section of the system	Type of worker				
	Maintenance man				Mechanical
	Laborer	Electrical	Plumber	Wastewater treatment operator	
Scrubber	X				
Separator	X				
Fan		X			
Pump		X	X		X
Piping, valves			X		
Water treatment equipment		X	X	X	X

some of the fine particulate to pass through the interstices between the fibers. After a short time, however, a dust cake builds up on the surface of the bags and becomes the actual filtering medium. The bags then act as a matrix to support the dust cake.

Buildup of the dust cake is desirable up to a certain pressure drop, at which point the bags must be cleaned. Improper cleaning will cause the pressure drop to increase, and at a high enough pressure drop, particles of dust may be forced into the bag filter, causing the bags to become "blinded." When this happens, air flow is restricted and the bags may have to be replaced or removed and cleaned to restore proper operating capacity. In addition to the costs of replacement and cleaning, high pressure drop increases the cost of moving air through the system.

A typical reverse air or shaker type baghouse is shown in Figure 3-4, and a pulse type baghouse is present in Figure 3-5.

3.4.2 Preoperational Checks

The following checks are recommended prior to start-up:

- ° Test control air lines (hydrostatically).
- ° Check air dryers that supply control air to the bag filters.
- ° Check dust removal system.

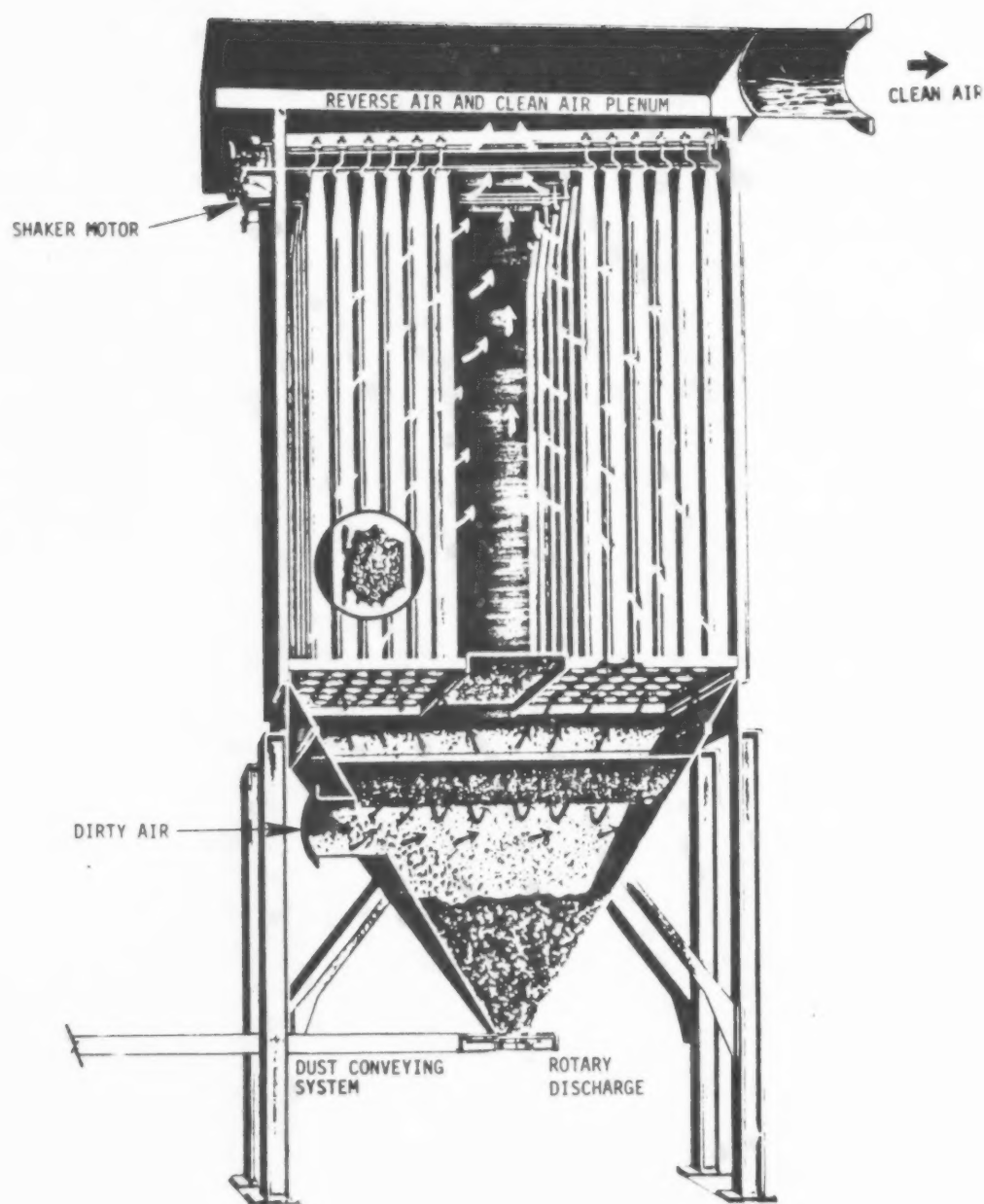


Figure 3-4. Reverse air or shaker type baghouse.

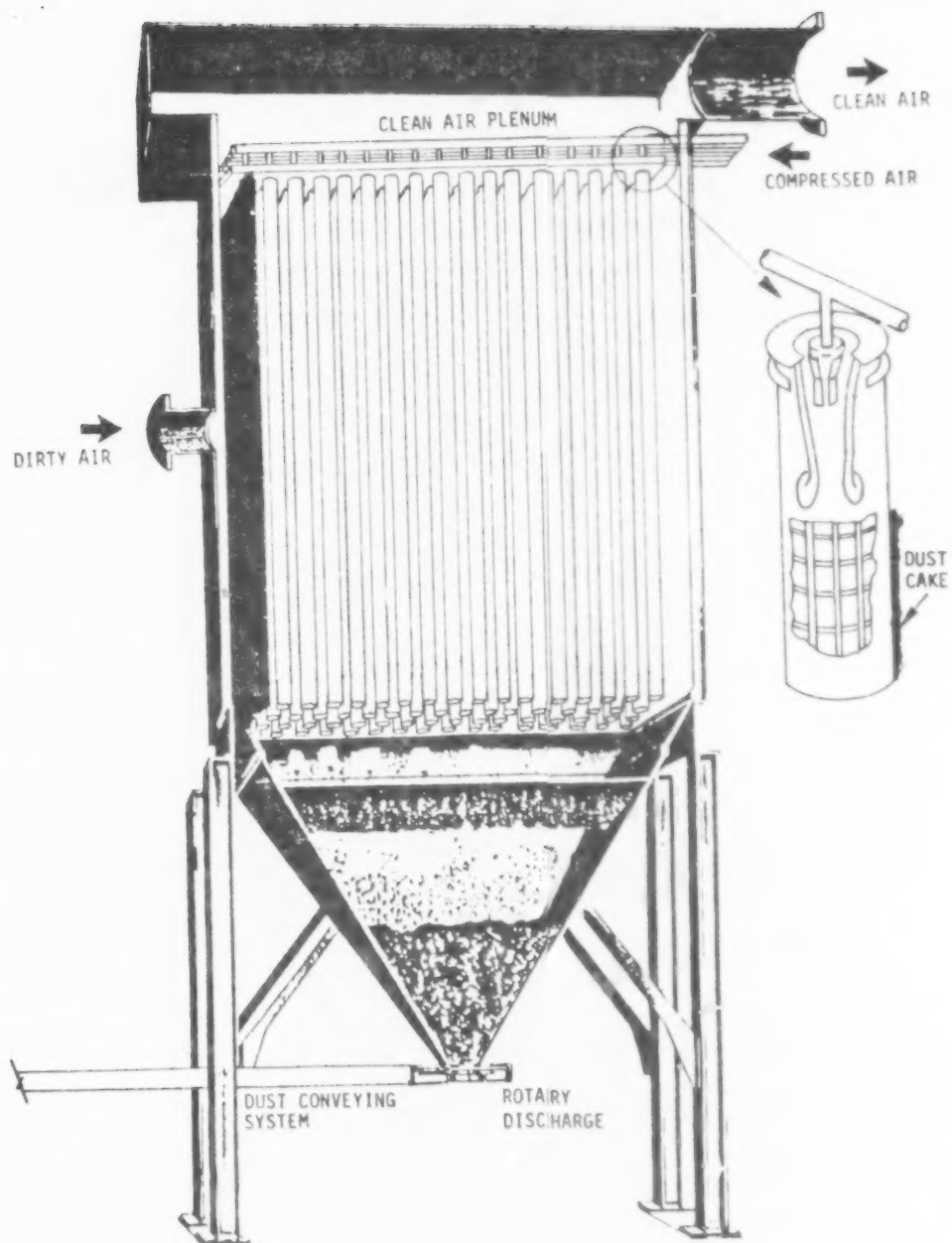


Figure 3-5. Pulse jet type baghouse.

- ° Inspect collapse air fans for alignment and rotation.
- ° Check seals at gas inlet, collapse air, and gas outlet damper.
- ° Check baghouse compartments, remove debris.
- ° Check filter bags for proper installation and tension.
- ° Check and sweep thimble floors clean. Dust buildup on floor during operation is a positive indication of a broken bag.
- ° Calibrate pressure drop recorders and transmitters.
- ° Check pressure taps for leakage.

3.4.3 Start-up

The operation of a fabric filter system is virtually completely automatic. However, start-up and shutdown are extremely critical.

When the new equipment is started for the first time, the fan should be checked for correct direction of rotation and speed. The ducting, collector housing, etc., should be checked for leaks. Gas flows and pressures should be checked against the design specifications. Instruments should then be checked for correct reading and calibration adjustments made as necessary. Control mechanisms, and especially all fail-safe devices, should be checked for operability.⁸

At the first start-up of the system, and also whenever new bags have been installed by the maintenance crew, the

bags should be checked after a few hours of operation for correct tension, leaks, and expected pressure differential. Initial temperature changes or the cleaning cycle can pull loose or burst a bag. It is wise to record at least the basic instrument readings during this start-up period on new bags, for ready reference and comparison during later start-ups.⁸

During any start-up, transients in the dust generating process and surges to the filter house are probable and ought to be anticipated. Unexpected temperature, pressure, or moisture has often badly damaged a new installation. In particular, running almost any indoor air or combustion gases into a cold filter can cause condensation on the walls and cloth, leading to blinding and corrosion. Condensation in the filterhouse may void the manufacturer's guarantee. It can be avoided by preheating the filter or the gas.⁸

A typical sequenced start-up procedure for a large continuous automatic multicompartment fabric filter using either reverse air, shake, or combination cleaning could be summarized as follows:

1. Check to see that all system monitoring instruments are reading zero; especially fan motor ammeters and compartment pressure manometers.
2. Close all system dampers except tempering air damper (if used). This includes main compartment isolation dampers, reverse air dampers (if used), and fan modulation dampers.

3. Start material handling system including any motorized airlock devices and screw conveyors. Hoppers should be empty on start-up.
4. Sequentially start main fans allowing each to come to speed before starting next fan.
5. Start separate reverse air fan if used and allow to come to speed.
6. Engage fan modulating damper circuit(s).
7. Engage tempering air damper circuit (if used).
8. Slowly open main compartment isolation dampers. If dampers are opened too quickly bags will pop open, ultimately resulting in failure.
9. Engage compartment cleaning circuit.
10. Check normalcy of readings on system monitoring instruments; especially fan motor ammeters and compartment pressure manometers.

The main precaution in shutting down the filter system is prevention of moisture in the filterhouse. Condensation can appear through the cooling of gases containing moisture, particularly combustion gases, if they are not completely purged from the filter system and replaced with drier air before the filter cools down. This can also happen with air at ambient moisture levels if the filter is in a colder location. To prevent condensation, the systems should be purged carefully on shutdown and then sealed off completely. Alternately, a flow of warm air can be continued through the filter during the shutdown, which also helps prevent condensation when it is started up again. A shutdown procedure is summarized below:

1. After process has been stopped and emissions have ceased, allow baghouse to track through one complete cleaning cycle; this will purge system of process gas and collected dust.
2. Stop main fans.
3. Stop separate reverse air fan if used.
4. Allow material removal system to operate for 1 hour or until system is purged of collected material.

Automatic operation extends to relatively complicated applications, such as combination fourth-hole and canopy ventilation of electric arc steel furnaces. Here, limit switches on the furnace open or shut the appropriate dampers during each phase of the furnace cycle so that the canopy section over the furnace is open during charging and back charging; the direct evacuation system is operational during meltdown and refining; and the canopy over the teeming aisle is open during pouring. In addition, if the canopy over the furnace is left about 10 percent open during meltdown, it will scavenge any emission that escapes the direct furnace evacuation system.

3.4.5 Maintenance During Normal Operation

Maintenance of fabric filters in the iron and steel industry centers around the bags and the moving mechanical parts in the hostile interior of the baghouse (i.e., dampers, screw conveyors, and shaker linkages). The same maintenance

procedures can be applied to baghouses operating on a sinter plant or on electric arc furnaces in the steel or ferroalloy industries.

Table 3-8 presents a checklist of items that require regular inspection.

Plant personnel must learn to recognize the symptoms that indicate potential problems in their fabric filter, determine the cause of the problem and remedy it, either by in-plant action or by contact with the manufacturer or other outside resource.

For example, high pressure drop across the system is one symptom for which there could be many causes, e.g., difficulties with the bag cleaning mechanism, low compressed-air pressure, weak shaking action, loose bag-tension, or excessive reentrainment of dust. Many other factors can cause excessive pressure drop, and several options are usually available for corrective action appropriate to each cause. Thus the ability to locate and correct malfunctioning baghouse components is important and requires a thorough understanding of the system. A detailed list of troubleshooting and corrective measures is given in Appendix C-4.

Table 3-9 presents the frequency of failure of basic fabric filter parts, including the frequency of inspection and inspection time, as well as the time required for repairs.

Table 3-8. CHECKLIST FOR ROUTINE INSPECTION OF BAGHOUSE⁶

Component ^a	Check for:
Shaker mechanism (S)	Proper operation without binding; loose or worn bearings, mountings, drive components; proper lubrication.
Bags	Worn, abraded, damaged bags; condensation on bags; improper bag tension (S) (RF); loose, damaged or improper bag connections.
Magnehelic gauge or manometer	Steadiness of pressure drop (should be read daily).
Dust removal system	Worn bearings, loose mountings, deformed parts, worn or loose drive mechanism, proper lubrication.
Baghouse structure (housing, hopper)	Loose bolts, cracks in welds; cracked, chipped, or worn paint; corrosion.
Ductwork	Corrosion, holes, external damage, loose bolts, cracked welds, dust buildup.
Solenoids, pulsing valves (RP)	Proper operation (audible compressed air blast).
Compressed air system (RP, PP)	See above; proper lubrication of compressor; leaks in headers, piping.
Fans	Proper mounting, proper lubrication of compressor; leaks in headers, piping.
Damper valves (S, PP, RF)	Proper operation and synchronization; leaking cylinders, bad air connections, proper lubrication, damaged seals.
Doors	Worn, loose, damaged, or missing seals; proper tight closing.
Baffle plate	Abrasion, excessive wear.

^a RP-reverse pulse; PP-plenum pulse; S-shaker; RF-reverse flow.

Table 3-9. BAGHOUSE COLLECTOR MAINTENANCE⁶

Item	Frequency of breakdown	Frequency of inspection	Time required to perform inspection	Time to repair	Type of person to repair	Comments
INSIDE BAG COLLECTION						
<u>Bags</u>						
5 in. Ø 14 ft	Monthly	Monthly	1.5-3 man-h/100 bags ^a	10-30 min/bag ^b	Laborer ^c	Complete replacement 2 years same. Same
8 in. Ø 22 ft	Monthly	Monthly	2-4 man-h/100 bags ^a	15-45 min/bag ^b	Laborer ^c	
12 in. Ø 30 ft	Monthly	Monthly	2.5-5 man-h/100 bags ^a	20-60 min/bag ^b	Laborer ^c	
<u>Door seals</u>	2-4 yr	Monthly	5 min/door	1 h/door	Laborer	
<u>Cleaning mechanism</u>						
Shaker	6 mo	Monthly	5-min/row	30 min/row	Maint. man	
Reverse air	2 yr	Monthly	15 min	2 h	Maint. man	
<u>Dust removal system</u>						
Screw conveyors	1-2 yr	6 mo	1 h	2-4 h	Maint. man	
Air locks	1-2 yr	6 mo	30 min	1-2 h	Maint. man	
Pneumatic	2-3 yr	6 mo	1 h	8 h	Maint. man	
<u>Baffle plate</u>	4 yr	1 yr	30 min	8 h	Maint. man	
<u>Damper valves</u>	2-3 yr	Monthly	15 min/valve	1-24 h	Maint. man	
OUTSIDE BAG COLLECTOR						
<u>All bags</u>	Monthly	Monthly	0.6 man-h/100 bags	6-10 min/bag	Laborer	Assume top bag removal
<u>Cleaning mechanism</u>						
Pulse jet	2 yr	Monthly	2 min/row	30 min	Maint. man	
Pulsing plenum	2 yr	Monthly	2 min/row	1 h	Maint. man	
<u>Door seals</u>	2-4 yr	Monthly	5 min/door	1 h/door	Laborer	
<u>Dust removal system</u>						
Screw conveyors	1-2 yr	6 mo	1 h	2-4 h	Maint. man	
Air locks	1-2 yr	6 mo	30 min	1-2 h	Maint. man	
Pneumatic	2-3 yr	6 mo	1 h	8 h	Maint. man	
<u>Baffle plates</u>	4 yr	1 yr	30 min	8 h	Maint. man	
<u>Damper valves</u>	2-3 yr	Monthly	15 min/valve	1-24 h	Maint. man	

^a 1.5 man-h. bag for 24 in. reach, 3.0 man-h/100 bags for 36 in. reach (time may be cut by 70% if rejection of fluorescent particles and black light are used).

^b Low value is total changeout/bag and high value is individual bag change.

^c Three-man crew minimum.

Following is a discussion of major fabric filter components requiring routine maintenance:

3.4.5.1 Inlet Ducting - Common problems such as abrasion, corrosion, sticking or plugging of dust, and settling must be dealt with on a routine basis. Abrasion can be reduced by using special materials at bends in ducting, for example. Corrosion can be minimized by supplying insulation, especially in the long duct runs, which are most susceptible to moisture condensation. Regular inspection will help control plugging and settling problems in ducts.

3.4.5.2 Blast Gate and Flow Control - Problems with flow control equipment are reported frequently.⁸ The blast gate valve is especially vulnerable and should be checked periodically and adjusted. Filter compartment inlet dampers are a high-maintenance item, and spare parts should be stocked.⁸ A bad damper seal can shorten the life of bags in a shake-type system, and caking bags, if not replaced, can foul valves on the clean side of the baghouse and cause them to malfunction. The most popular dampers for compartment isolation are air cylinder-operated poppets acting vertically (see Figure 3-6). Several users mentioned problems with push rod guides when dampers were made to act horizontally. Maintenance on these dampers consists of periodic inspection and replacement of packing and solenoids. The wafer and seat were not indicated as presenting severe

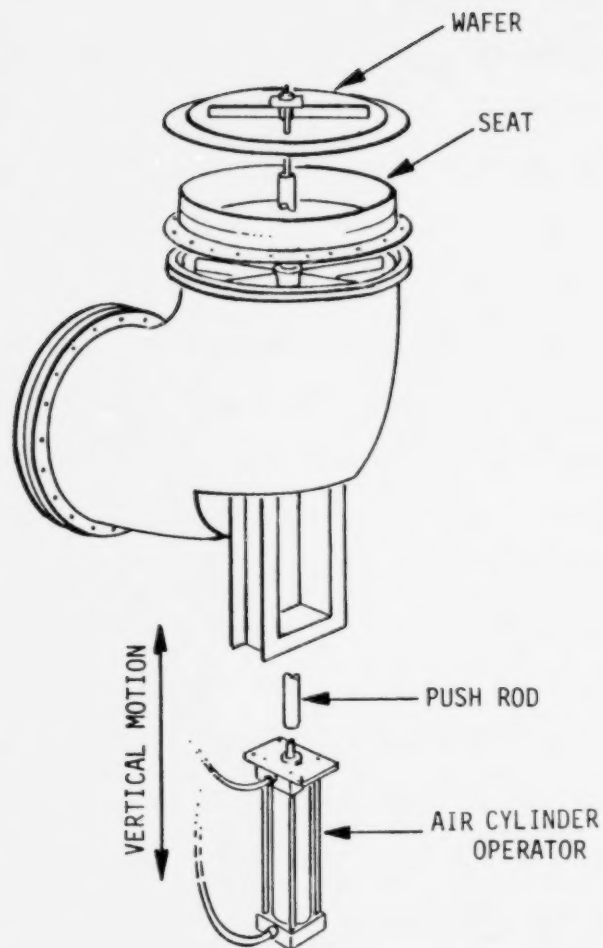


Figure 3-6. Poppet valve.

maintenance problems. Damper failures can sometimes be detected by observation of a differential pressure chart. As the dampers open and close, the differential pressure swings. If a damper fails, the absence of this pressure swing leaves a "gap" on the differential pressure chart. If a high differential pressure is signaled, the dampers are routinely checked for proper operation. If not, the operator must observe damper operation through the complete cycle directly at the baghouse.

3.4.5.3 Fans - Fans and blowers are reported to be a large problem area, particularly those located on the dirty side of the baghouse where material can accumulate on the vanes and throw off the balance.⁸ Corrosion and abrasion can also cause problems. The use of pressure style baghouses has been dramatically reduced however, because of the necessity for on-line maintenance, and the danger associated with working on a pressure type inside bag collector.

Condensation and corrosion in the fan may be alleviated with duct and fan insulation.⁸ Most fan housings can be drained, and the drains should be checked on a regular basis.

Air flow and fan speed should be measured periodically and belt condition and tension determined; the fan should also be checked for direction of rotation. These checks can be combined with routine lubrication procedures.

3.4.5.4 Entrance Baffles - Baffles may be added to improve distribution of the gas to each compartment and bag. They should be adjustable, however. They may cause problems by accumulating dust or abrading too rapidly.

3.4.5.5 Hoppers - Hoppers are a common problem in any fabric filter system. Dust flow can be facilitated by the use of vibrators and/or heaters (if they work properly); by lining the hoppers with anti-friction material; by the use of air-pulsed rubber-lined hoppers; by placing poke holes in the side of the hoppers; or by insulation if condensation is a problem.

Trough-type hoppers with integral screw conveyors are by far the most common material handling systems in the iron and steel industry. Dust storage in baghouse hoppers is a common industry practice, although this frequently results in dust bridging and subsequent sledgehammering of hoppers to break the dust bridge. Hopper vibrators are not generally used because of expense and the tendency of vibrators to pack the dust and aggravate the problem if vibration amplitude and frequency are not correctly selected.

Regular inspection (once per shift) of the hopper is mandatory to alleviate suction-removal system or bridging problems before they become serious.

The screw conveyor flighting inside the hoppers is supported every 10 to 15 feet by nonlubricated sleeve-type

hanger bearings (see Figure 3-7). Wear on these sleeves and on outboard packed bearings is the major screw conveyor maintenance problem. The most common sleeve material is cast iron, although Babbitt, wood, and various other material have been used.

3.4.5.6 Bag Replacement - The most expensive maintenance operation for fabric filter systems is the complete change of a set of bags. This is accomplished by having a crew of two to six men enter the baghouse and disconnect each bag at the cell plate and top suspension level and install a new bag in its place. Two bag attachment techniques are illustrated in Figure 3-8. The purchase price of replacement bags is given in Table 3-10. The bag life reported by respondents to the questionnaire survey is given in Table 3-11.

3.4.5.7 Tension - The amount of bag tension required for best overall performance varies according to the make of the equipment. Correct tension is a function of filter dimensions and cleaning mechanism. A bag that is too slack can fold over at the lower cuff, bridge across, and wear rapidly.⁸ Too much tension can damage the cloth and the fastenings. Shake cleaning in particular seems to require a unique combination of tension, shake frequency, and bag properties for best results.⁸ In any event, the manufac-

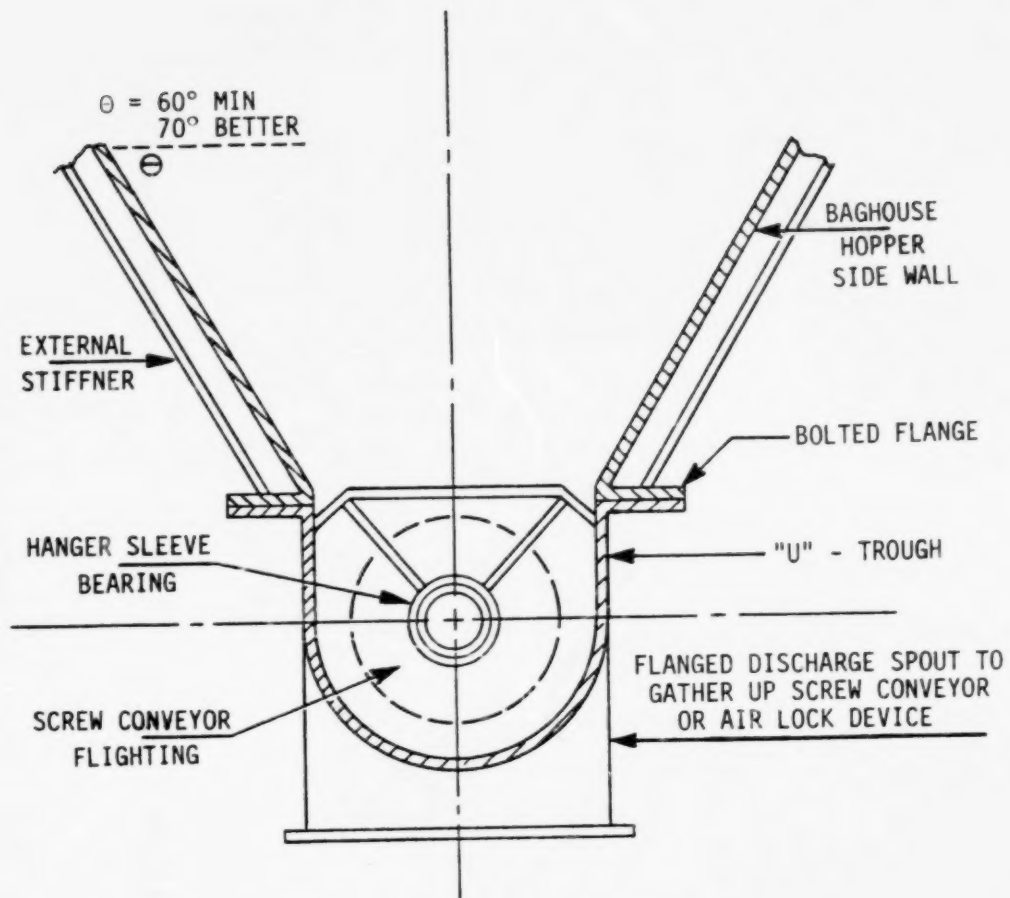


Figure 3-7. Typical trough hopper and screw conveyor arrangement.

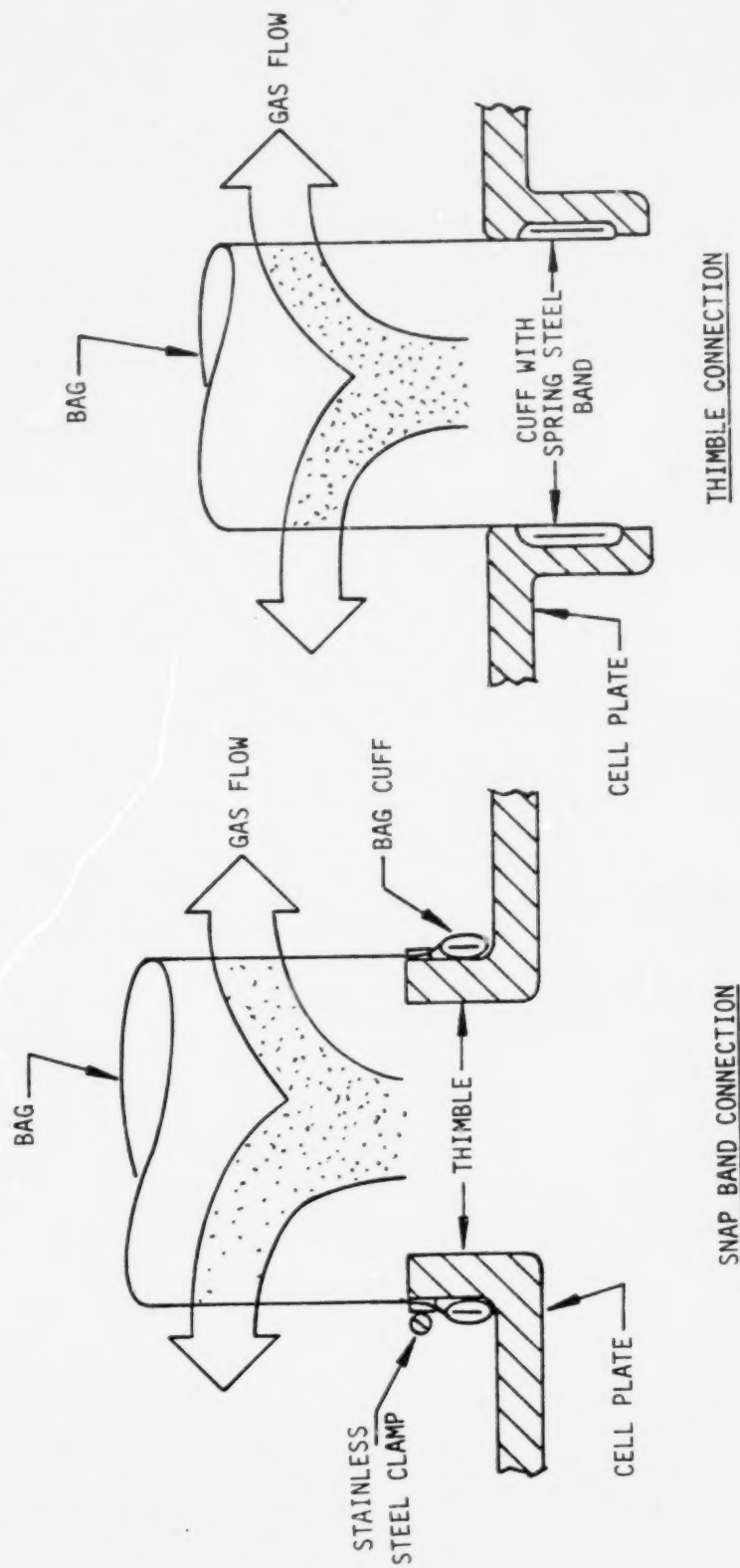


Figure 3-8. Bag-cell plate attachments.

Table 3-10. APPROXIMATE COST OF REPLACEMENT BAGS

Material	1977 cost (dollars)
Nylon (5.3 oz/yd ²)	0.64/ft ²
Sewn in ring	2.00 each
Polyester (7 oz/yd ²)	0.31/ft ²
Sewn in ring	1.30 each
Fiberglass (silicon/graphite finish; 9 oz/yd ²)	0.26/ft ²
Sewn in ring	1.25 each
Fiberglass (10% PTFE finish; 9 oz/yd ²)	0.42/ft ²
Sewn in ring	1.50 each
Top caps (mild steel, 12 in. dia)	2.80 each
Stainless steel clamps	1.75 each

Table 3-11. BAG LIFE IN THE IRON AND STEEL INDUSTRY

Application	Bag life (months)	
	Range	Average
Ferroalloy	-	48
Electric arc steel	18-72	55
Sintering	18-60	27

turer's recommendations should be followed and the tension checked periodically, especially a few hours after installing a new bag.

3.4.5.8 Spare Stock - It is advisable to have a complete set of filter elements in stock in case of an emergency. The spare filter elements should be clearly labeled and kept well-separated from used filter elements.⁸ Table 3-12 presents a typical list of items that should be stocked, the approximate quantities, and if the parts are not stocked, the approximate delivery time and cost.

3.4.5.9 Inspection Frequency - External maintenance inspection of the filter house is usually performed daily, whereas the filter elements themselves are typically inspected once a week to once a month.⁸

3.4.5.10 Shake Cleaning - Shaker mechanisms are generally simply supported from each end by knife-edge bearings set in grooved blocks. A fractional horsepower motor is used with a yoke linkage to oscillate the shaker bars (see Figure 3-9). Shaker mechanism maintenance is centered around the drive arrangement. Periodic lubrication of bearings and checking of alignment are required. The shaking machinery should also be checked periodically for wear. If the bags are not being cleaned properly, sometimes a minor adjustment of the shake amplitude or frequency can markedly improve

Table 3-12. LIST OF REPLACEMENT PARTS FOR A BAGHOUSE FILTER⁶

Type of part	% of total parts in baghouse that should be stocked	Delivery time if not stocked, weeks	Estimated cost	Comments
Bags	15	4-8	See Table 3-10	Typical 18" x 48" door
Door seals	20	2-4	10/seal	
Mechanism				
Shaker	20	2-4	10/item	Bearings, knife blades, belts
Reverse air	100	6-10	25/item	Belts
Pulse jet	20	2-4	3/item	Valve rebuild kit
Pulsing plenum	20	2-4	5/item	Solenoid valves, seals, cylinders
Screw conveyor	20	8-10	10/item	Bearings
Air locks	100	8-10	10/item	Seals
Pneumatic		8-10		Variable
Baffle plates		4-6	100/plate	
Damper valves	20	4-6	10/item	Solenoid valves, seals, cylinders

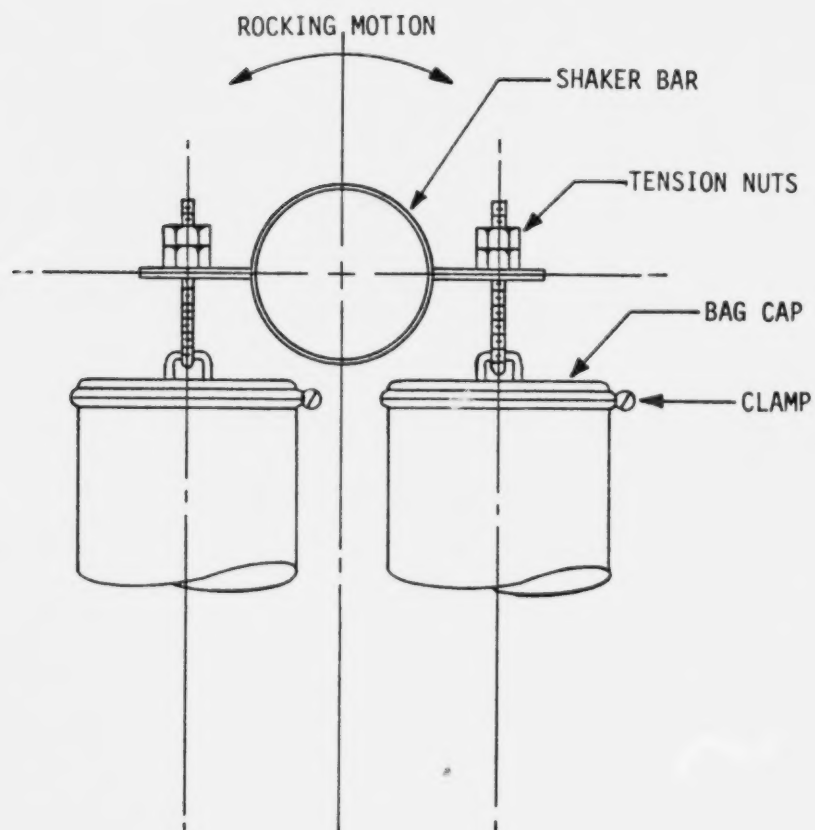


Figure 3-9. Typical shaker arrangement.

cleaning. If a safe amount of shaking still does not properly clean the clots, it may be necessary to reduce the filtration velocity for a few hours.⁸

3.4.5.11 Reverse-Flow Cleaning - With this type of cleaning, the only maintenance requirement is to check the rate of flow (back pressure) and the timing periodically to keep the residual drag at an economical level.

3.4.5.12 Shake and Reverse-Flow Cleaning - As in the case of shake cleaning, wherever the bag is flexed the rate of wear is apt to be high. Maintenance procedures outlined for the shake and reverse-flow methods also apply here.

3.4.5.13 Pulse Jet Cleaning - Since there are almost no moving parts in the pulse type apparatus, hardware maintenance is reduced in comparison with other cleaning methods. However, excessive use of air cleaning pressure can damage bags by overstretching them. Corrective measures include reduction of the frequency of cleaning, the use of another type of bag fabric, or reduction of the abrasiveness of the dust.

3.4.5.14 Instrumentation - Proper operation of fail-safe mechanisms and automatic control instrumentation is very important to the safety of the filter cloth.⁸ The location of all sensing instruments should be checked to see that the proper temperature, air flow, etc. are being measured. All

instruments should be calibrated after installation and rechecked monthly for sensor location, leaks (manometer), sticking, and legibility.⁸ Instrument readings covering one complete operating cycle should be recorded for future use in routine checks and troubleshooting. This record should be posted beside each instrument.

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4.0 FRACTIONAL EFFICIENCY RELATIONSHIPS

4.1 INTRODUCTION

This section evaluates the fractional efficiency capabilities of precipitators, scrubbers, and fabric filters on selected iron and steel and ferroalloy processes. However, the availability of fractional efficiency test data for conventional particulate control devices is very limited. Numerous contacts with users and manufacturers have yielded no fractional efficiency test data. One set of test data was obtained from the Fine Particle Emissions Inventory System computer bank, for a precipitator serving seven open hearth furnaces. Another set of data was available from a test of a venturi scrubber on a ferroalloy furnace in Russia and one additional test run was obtained from the literature for a fabric filter operating on two electric arc furnaces.

Results from computer models are presented which predict percent penetration as a function of particle size for precipitators and wet scrubbers on iron and steel and ferroalloy processes.

Insufficient data are available for predicting the fractional efficiency of wet precipitators, and an appropriate computer model is not available for use with fabric filters.

4.1.1 Limitation of Current Data

Only in the past 4 or 5 years has particle size distribution been measured and recorded with any regularity by control equipment manufacturers, independent testing companies, and consultants; and because of operator error and the inherent technical limitations of some particle-sizing instruments, reliable data are still not readily available. Meaningful evaluation of fine particulate emissions will require development of a reliable and consistent fine-particle measuring technique that can be applied widely. A broadly applicable technique for compliance monitoring of fine-particle sources would have the added advantage enabling the collection of valuable data concerning various iron, steel, and ferroalloy processes under different operating conditions.

4.1.2 Summary of Inlet Particle Size Distribution Data Used for Precipitator and Scrubber Models

Table 4-1 summarizes the inlet particle size distribution data used in the precipitator and scrubber model predictions. These particle size distributions are based on a 1974 fine particulate inventory by Midwest Research Institute,

Inc.¹ This report presents particle fractions in the size range of 7 μm or less. Log normal plots of particle size distribution were developed from this data, resulting in the means and standard deviations presented in Table 4-1.

4.2 PROCEDURES FOR DETERMINING FRACTIONAL EFFICIENCY PERFORMANCE

4.2.1 Electrostatic Precipitator Computer Model

The electrostatic precipitator computer model computes size distribution at the precipitator outlet, based on inlet size distribution and overall mass collection efficiency. From the inlet and outlet distributions, fractional efficiencies can be calculated directly.

4.2.1.1 Design Equations and Assumptions - The following relationships² are used in the program to determine particle collection as a function of particle size.

The electrical force on a charged particle in an electric field is given by:

$$F = qE_p \quad (1)$$

where E_p (by the Deutsch model) is the electric field strength at the precipitator collecting electrode. Table 4-2 provides a definition of all terms in meter-kilogram-second (mks) system units. The force opposing particle motion through the gas is:

$$f = 3\pi\mu dw_d/C \quad (2)$$

Table 4-1. SUMMARY OF INLET PARTICLE SIZE DISTRIBUTION DATA

INDUSTRIAL SOURCES	PARTICLE SIZE DISTRIBUTION ^a	
	$\bar{x}$	σg
Iron and Steel		
Open hearth furnace	.21	2.86
Basic oxygen furnace	.27	1.82
Electric arc furnace	.80	9.30
Sintering process w/o mc	70.	6.67
w/ mc	7.7	3.5
Scarfig process	NA	NA
Ferroalloy		
Electric arc furnace		
Ferrosilicon alloys	.19	3.00
Ferromanganese alloys	.78	2.12
Ferrochromium alloys	.86	4.19
Miscellaneous ferroalloys	.50	3.36

^aDerived from Weast, T.E., MRI Fine Particulate Emission Inventory and Control Survey Table 28, p. 69 (Reference 1).

NA = Not Available

Table 4-2. NOMENCLATURE FOR ELECTROSTATIC
PRECIPITATOR COMPUTER MODEL

A	=	precipitator collecting area, m^2
a	=	defined by equation (6), dimensionless
C	=	Cunningham correction factor, dimensionless
d	=	particle diameter, m
$\bar{d}$	=	geometric mean particle diameter, m
E_o	=	effective charging field, (V/m)
E_p	=	effective precipitating field, (V/m)
F	=	force, N
$f_1(d)$	=	inlet particle size distribution function, m^{-1}
$g(d)$	=	defined by equation (10), m
k	=	defined by equation (9), m^{-1}
Q	=	volumetric gas flow rate, m^3/s
q	=	particle charge, C
w	=	Deutsch effective migration velocity, m/sec
w_d	=	migration velocity for particle of diameter d, m/sec
ϵ_o	=	permittivity of free space, 8.86×10^{-12} F/m
$\bar{\eta}$	=	overall collection efficiency, dimensionless
η_d	=	collection efficiency for particles of diameter d
λ	=	mean free path of gas molecules, m
μ	=	gas viscosity, kg (m/s)
σ	=	geometric standard deviation of size distribution, dimensionless

Equating the forces and solving for the migration velocity of particles of size d:

$$w_d = \frac{qE_p C}{3\pi\mu d} \quad (3)$$

C is the Cunningham correction factor given by:

$$C = 1 + 2.5\lambda/d + 0.84\lambda/d \exp(-.435d/\lambda) \quad (4)$$

The particle charge q can be represented by the Cochet equation:

$$q = [(1 + \frac{2\lambda}{d})^2 + \frac{2}{(1 + 2\lambda/d)}] \pi\epsilon_o E_o d^2 \quad (5)$$

The Cochet equation accounts for particle charging by both field charging and diffusion charging mechanisms. This is important in analyzing the effects of particle size, since the charging mechanism changes from field to diffusion in the submicron range.

Combining (3) and (5) and defining

$$a = [(1 + \frac{2\lambda}{d})^2 + \frac{2}{(1 + 2\lambda/d)}] \quad (6)$$

the particle migration velocity for particles of size d becomes:

$$w_d = (\frac{\epsilon_o E_o E_p}{3\mu}) aCd \quad (7)$$

For particles of a single size, d, the Deutsch equation can be applied to calculate collection efficiency:

$$(1 - \bar{\eta}_d) = \exp[-\frac{w_d A}{Q}] = \exp[-(\frac{\epsilon_o E_o E_p A}{3\mu Q}) (aCd)] \quad (8)$$

defining new terms:

$$k = \frac{\epsilon_o E_o E_p A}{3\mu Q} \quad (9)$$

$$g(d) = aCd \quad (10)$$

the single-size efficiency equation becomes:

$$(1 - \eta_d) = \exp[-kg(d)] \quad (11)$$

The overall collection efficiency is found by integrating over the inlet size distribution, $f_1(d)$:

$$(1 - \bar{\eta}) = \int_0^\infty (1 - \eta_d) f_1(d) dd \quad (12)$$

Assuming a log normal inlet distribution, this becomes:

$$(1 - \bar{\eta}) = \frac{1}{2\pi \ln \sigma} \int_0^\infty \exp[-kg(d) - 0.5 \frac{(\ln d/\bar{d})^2}{\ln \sigma}] d \ln d \quad (13)$$

The above procedures can be used to determine outlet size distribution and fractional efficiencies (or percent penetration). An important effect that the program cannot model is that of reentrainment of particles on fractional efficiency.

4.2.1.2 Percent Penetration as a Function of Particle

Size - Predicted penetration as a function of particle size is presented for the various electrostatic precipitator applications in Figures 4-1 through 4-9. Use of the computer program shows the important result of a minimum in efficiency in the 0.2 - 0.4 μm particle size range. As mentioned previously, the program does not model the effect of particle reentrainment on predicted penetration. In the

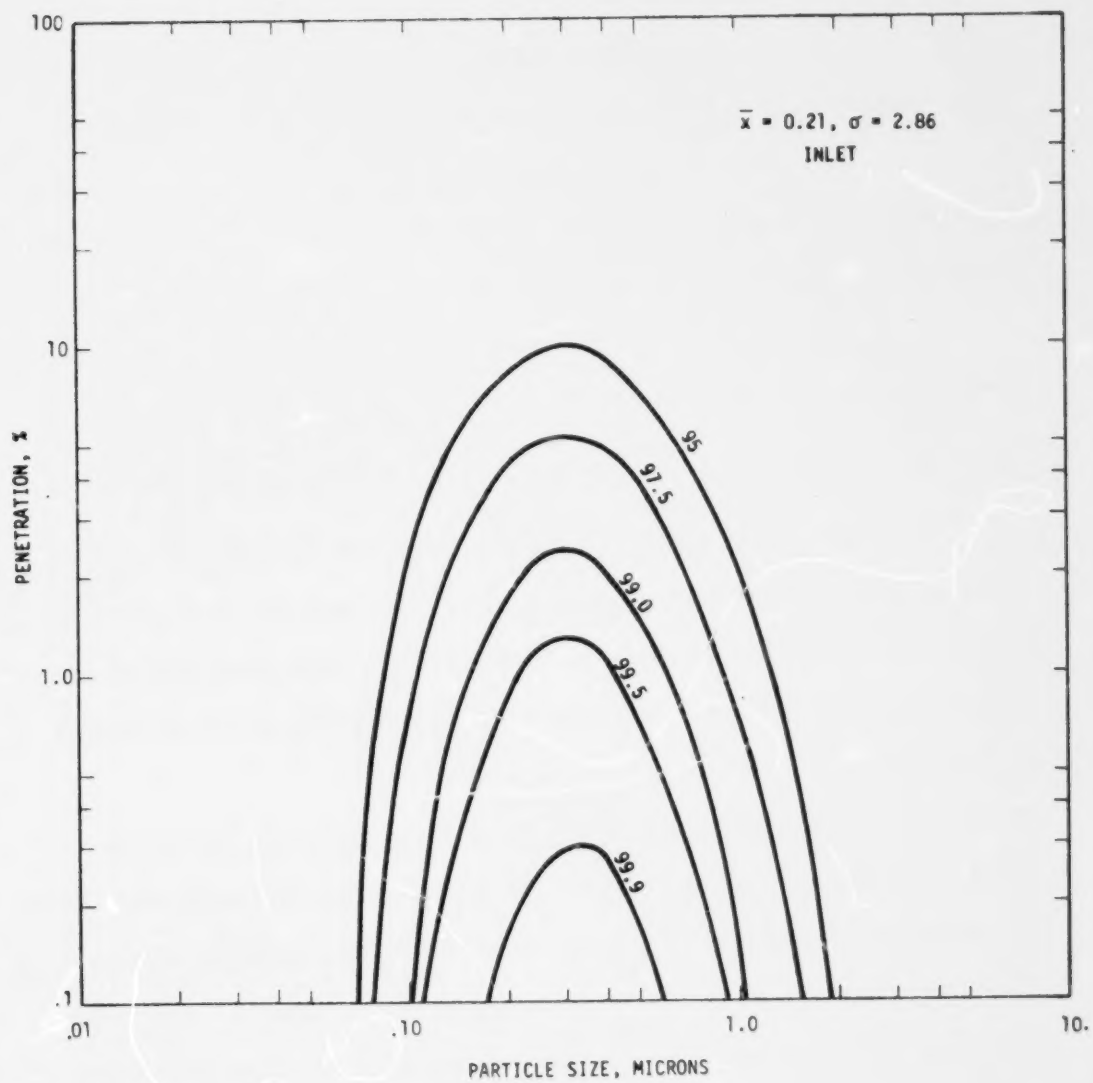


Figure 4-1. Cold precipitator penetration for open hearth furnace.

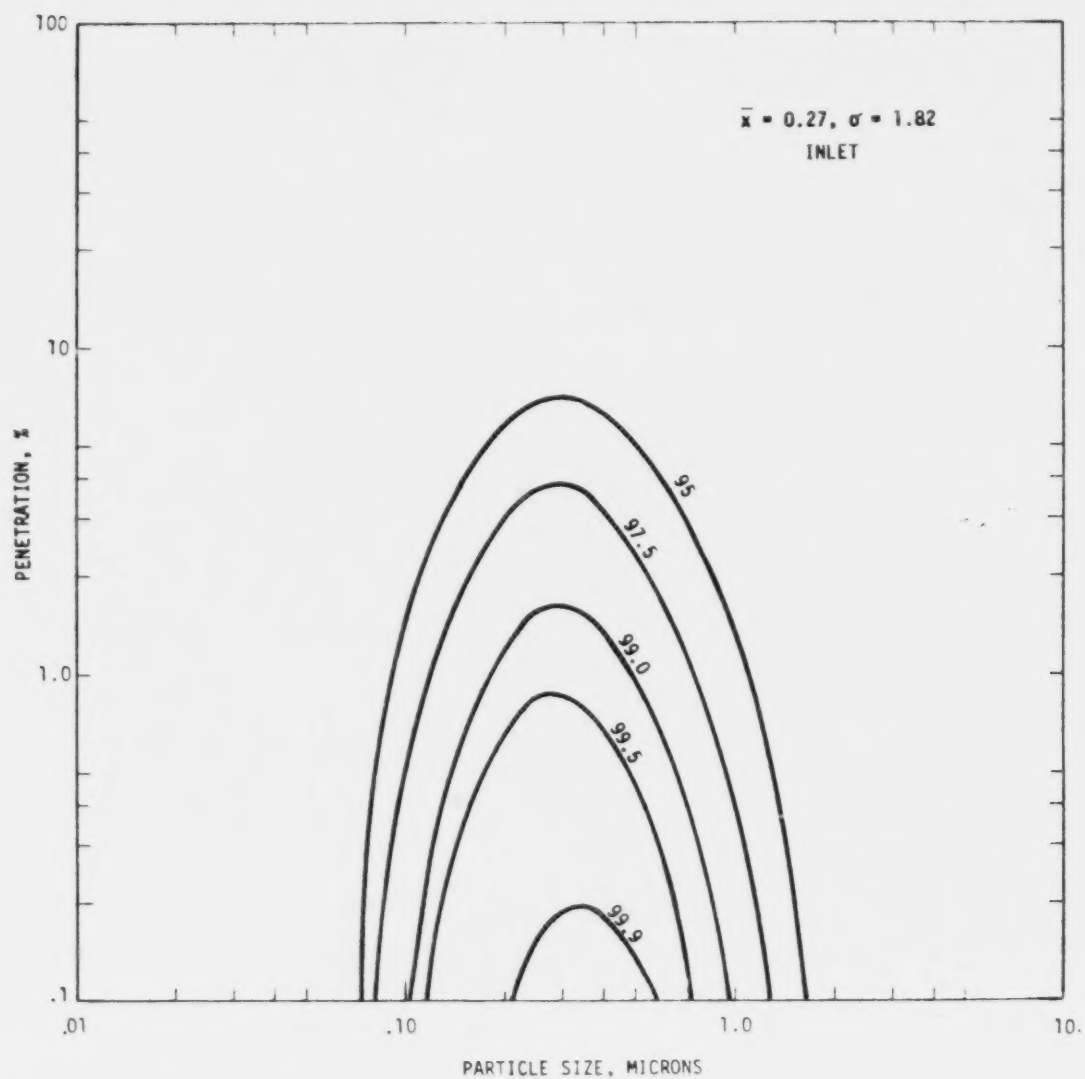


Figure 4-2. Cold precipitator penetration for basic oxygen furnace.

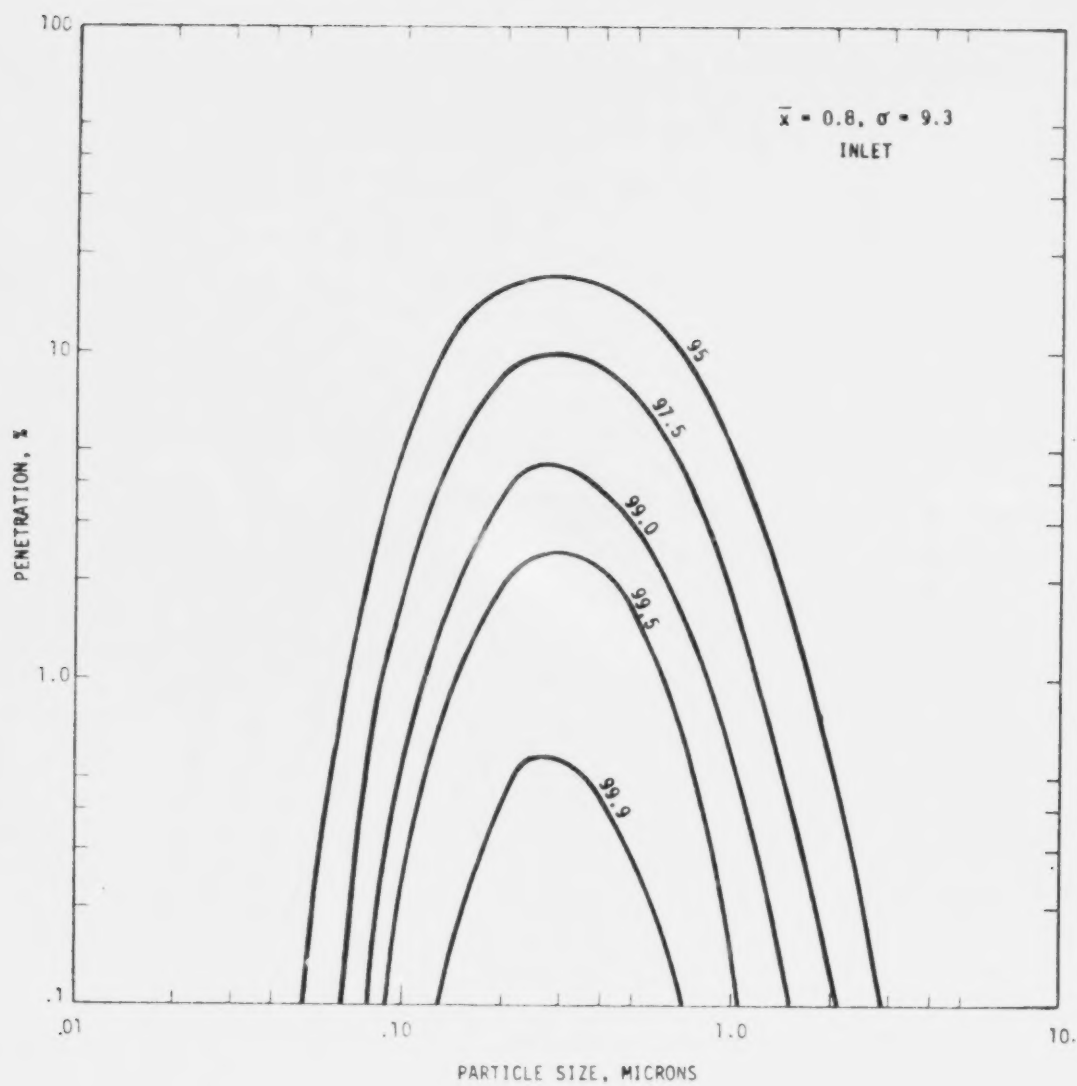


Figure 4-3. Cold precipitator penetration for electric arc furnace

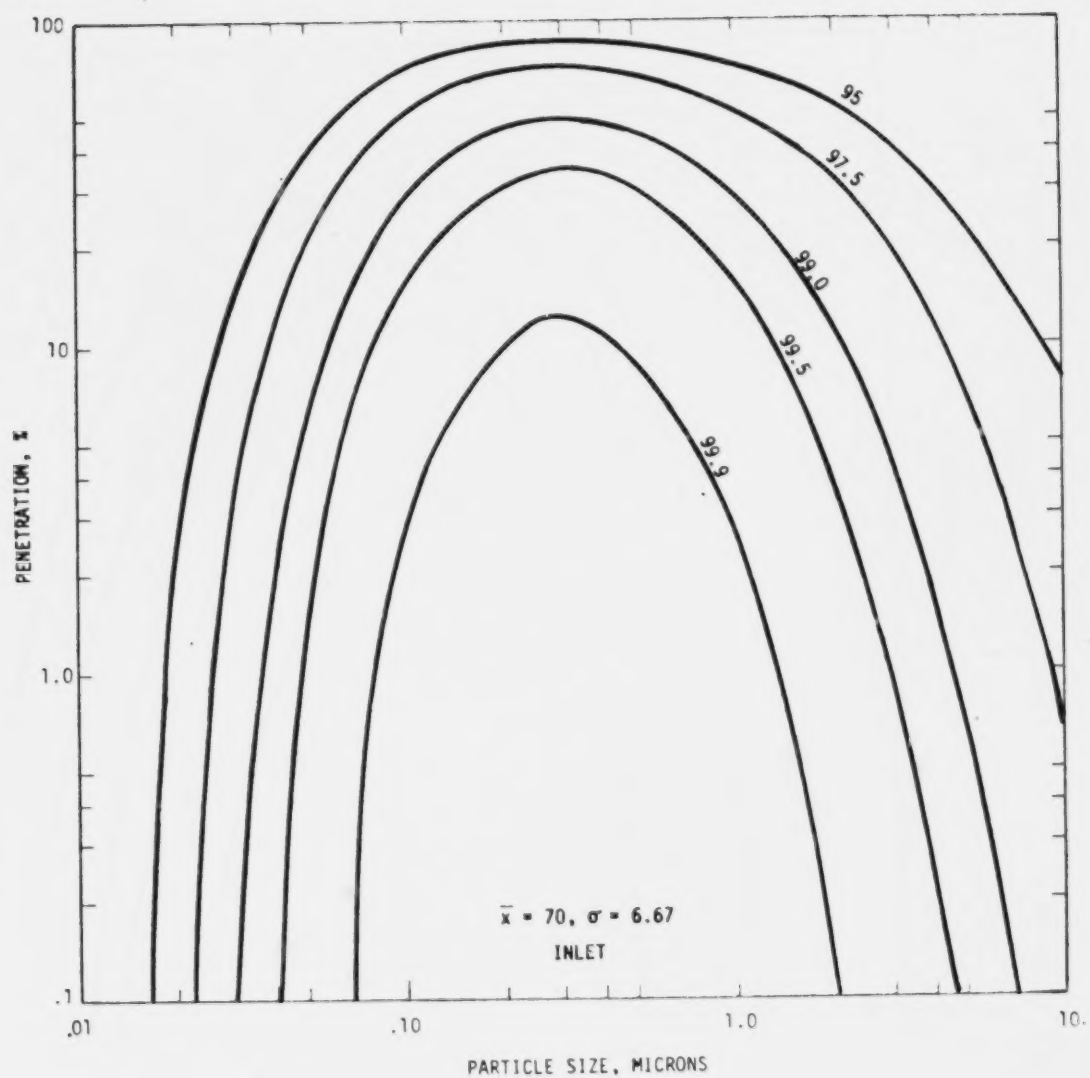


Figure 4-4. Cold precipitator penetration for sintering machine.

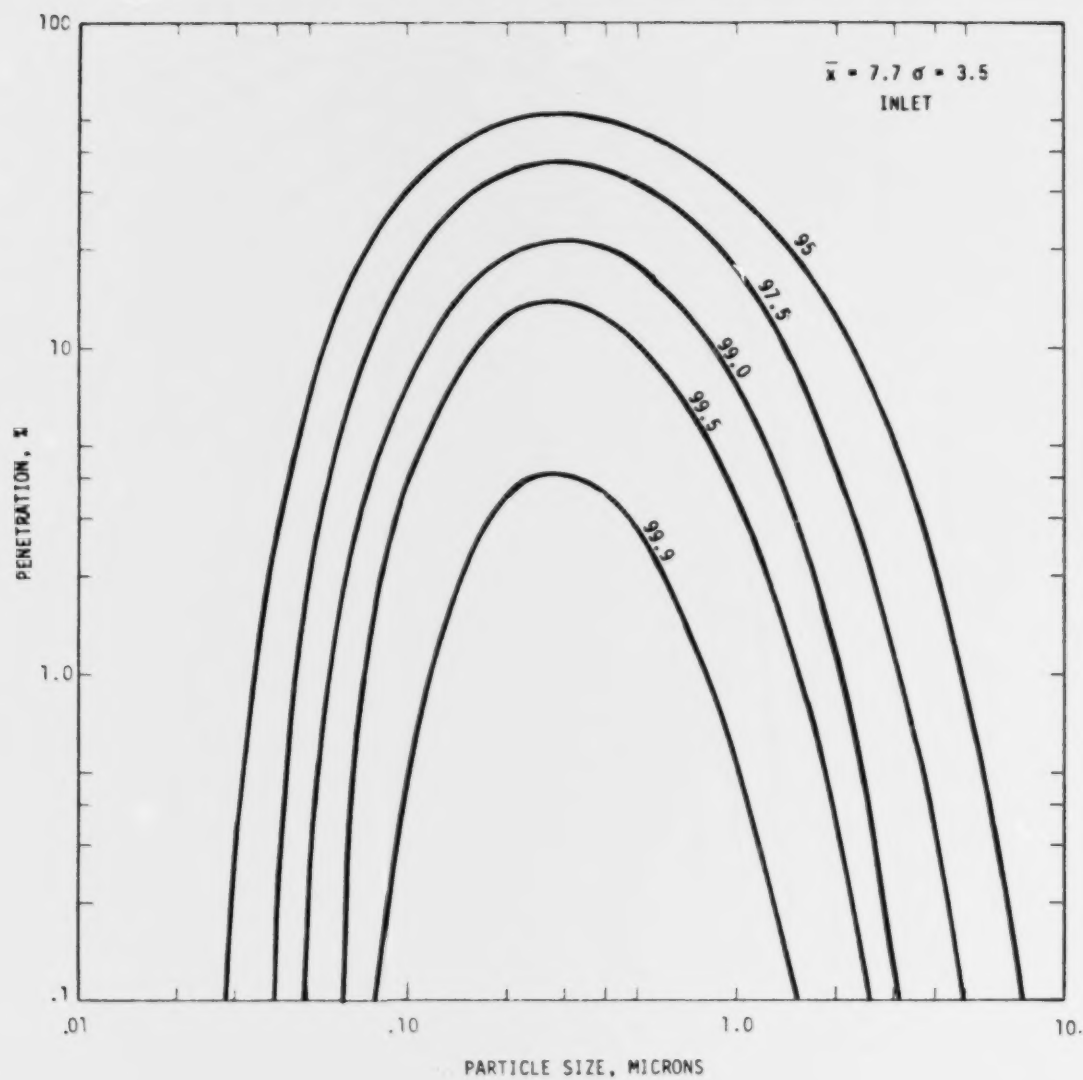


Figure 4-5. Cold precipitator penetration for sintering machine
(precipitator preceded by mechanical collector).

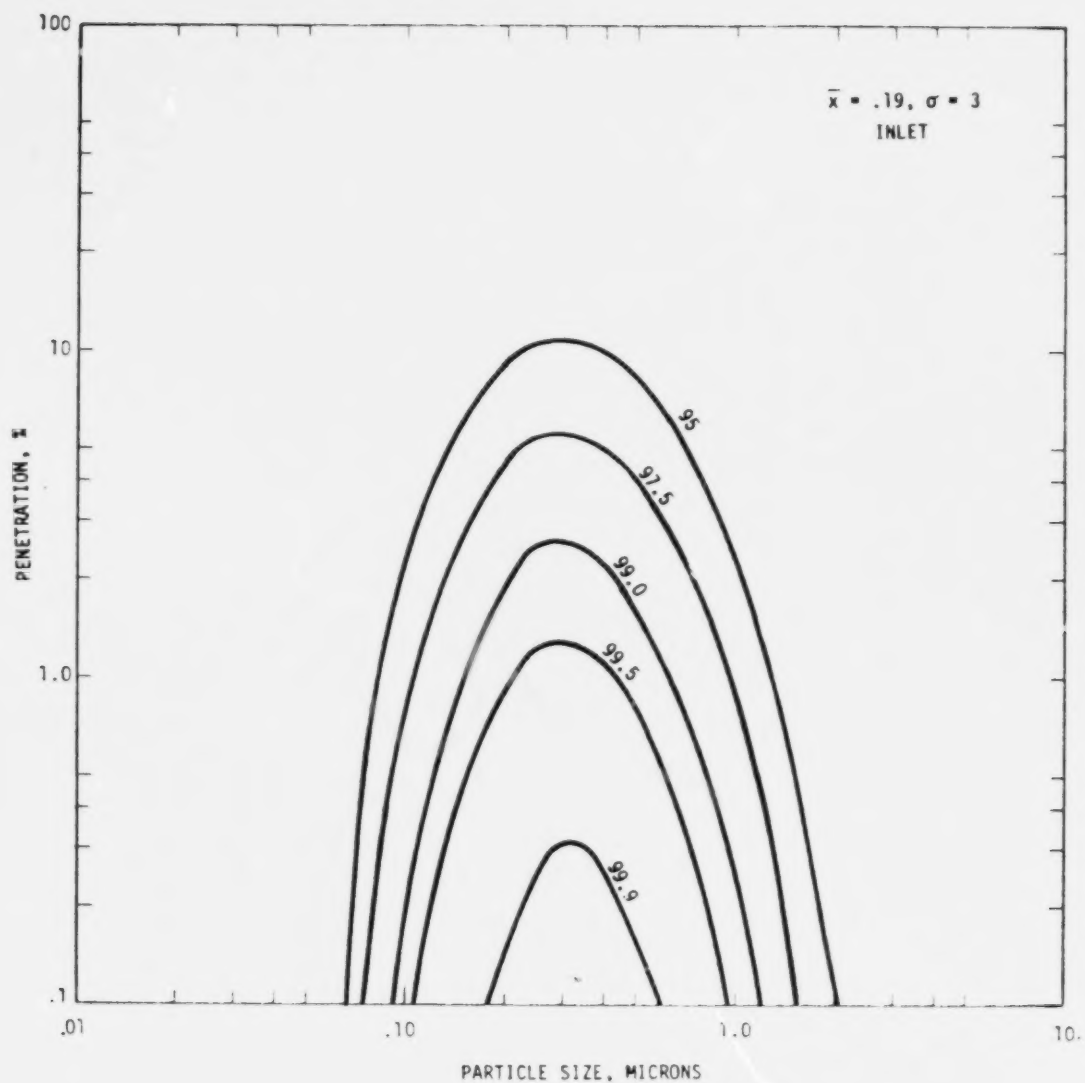


Figure 4-6. Cold precipitator penetration for ferrosilicon arc furnace.

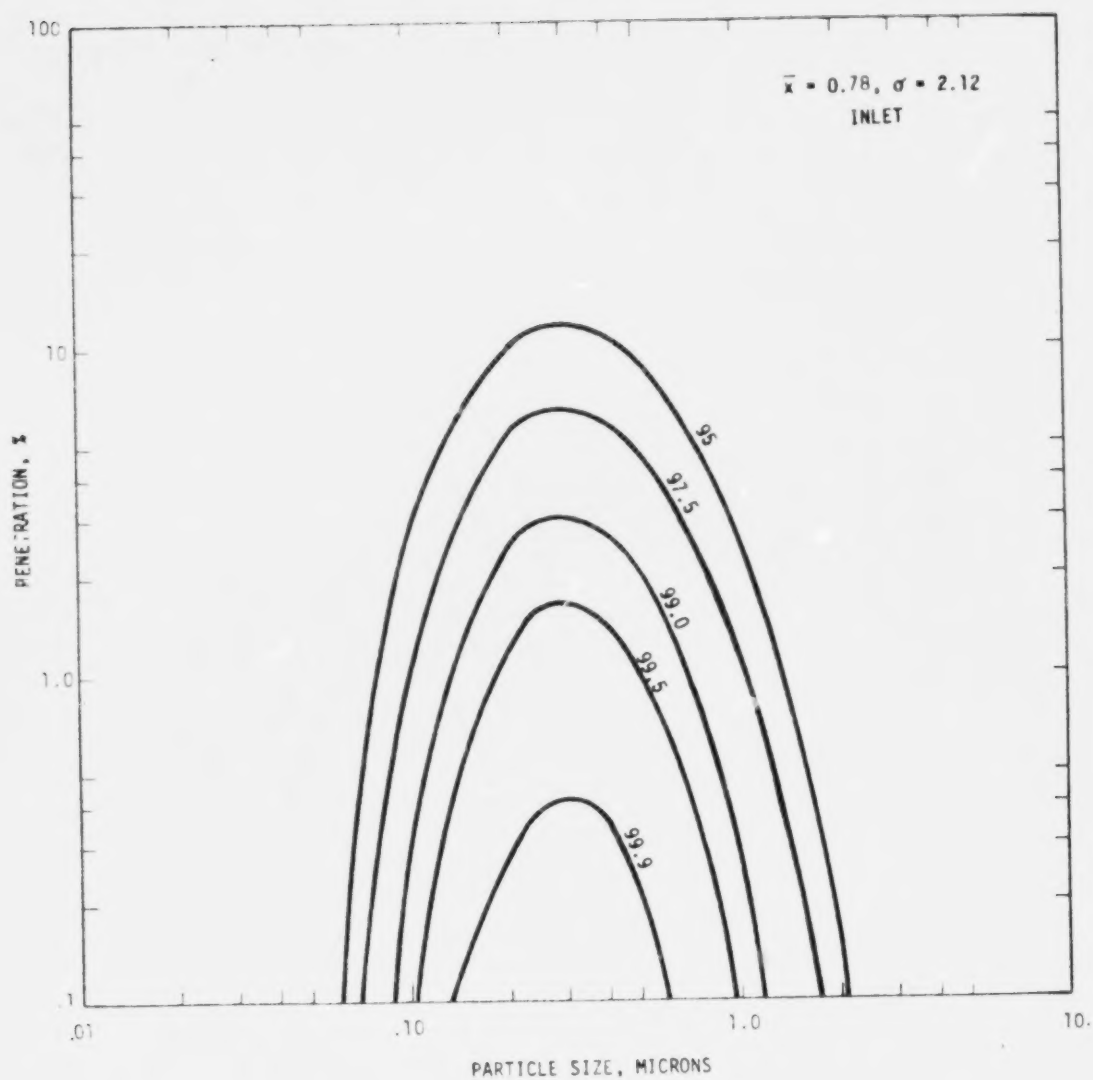


Figure 4-7. Cold precipitator penetration for ferromanganese arc furnace

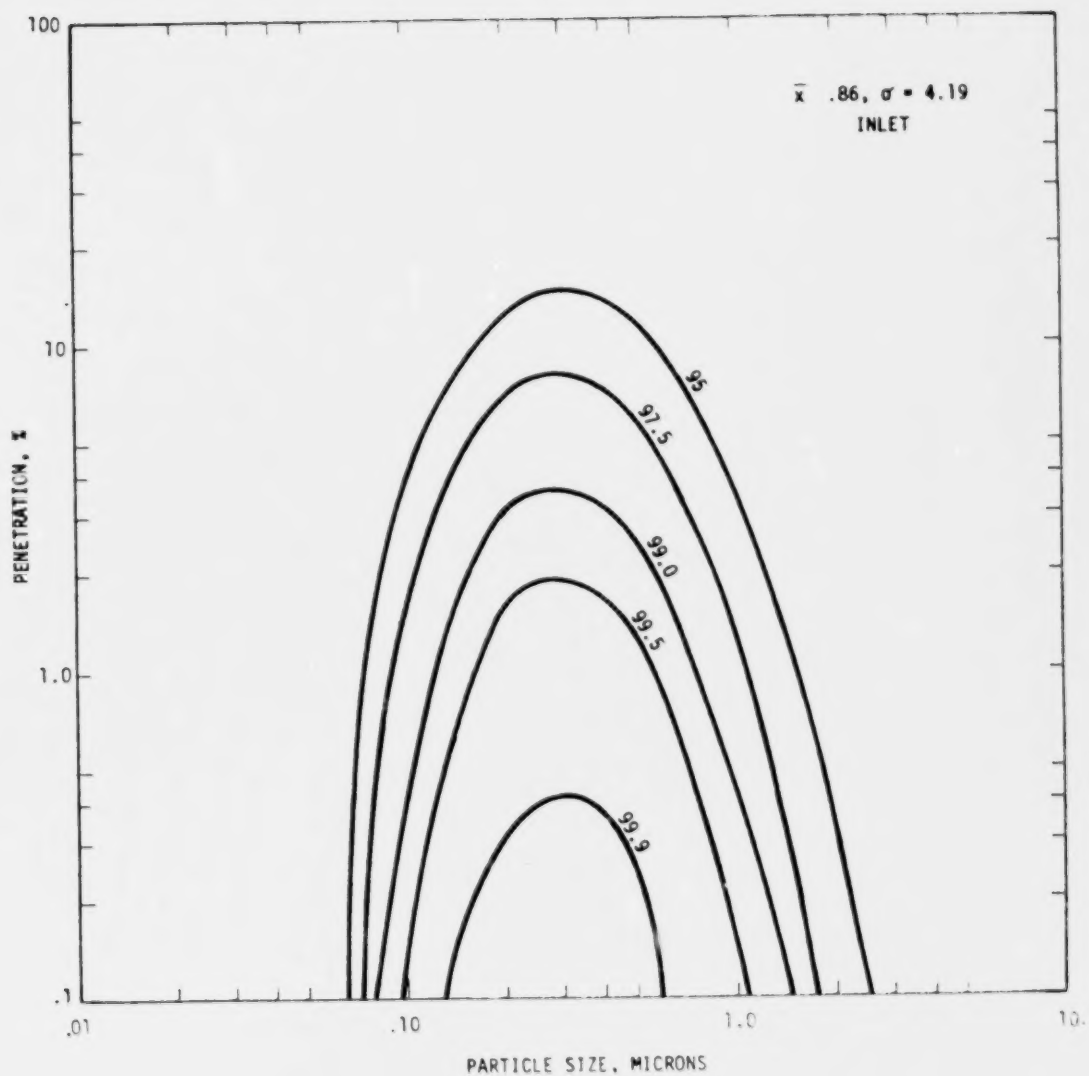


Figure 4-8. Cold precipitator penetration for ferrochromium arc furnace.

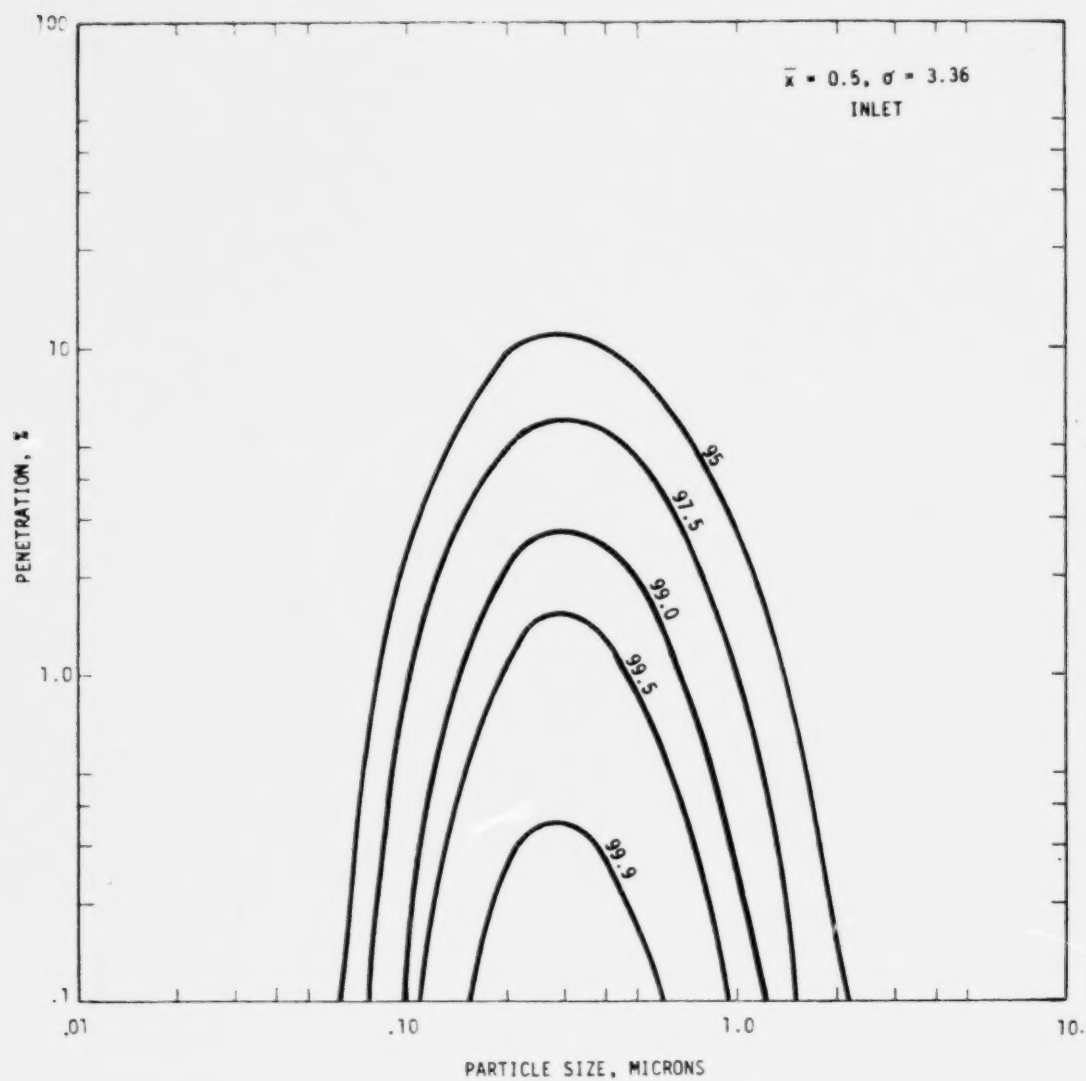


Figure 4-9. Cold precipitator penetration for miscellaneous ferroalloy arc furnace.

process of reentrainment, fine particles for agglomerates on the collecting plates are reentrained as larger particles. Thus, the measured fractional efficiencies must show a decrease in efficiency at larger particle sizes. For utility fly ash applications, an increase in penetration appears to occur in the neighborhood of 6 μm . Similar behavior with iron, steel, and ferroalloy applications is expected, although limited data are available to confirm this. Figure 4-10, for example, presents percent penetration as a function of particle size from a precipitator controlling off gases from an open hearth furnace. These test data show a decrease in efficiency in the 0.2 - 0.4 μm range, and another decrease in efficiency at 6 μm , presumably due to reentrainment effects.

Figure 4-11 shows percent penetration versus particle size at 99 percent overall mass collection efficiency for Basic Oxygen Furnace (BOF), Open Hearth Furnace (OHF), and Electric Arc Furnace (EAF) applications. The lower observed penetration predicted by the precipitator performance model for the BOF application confirms the explanation presented in Section 2.3.3 that BOF precipitators are more efficient than OHF or EAF precipitators.

One final point should be made with regard to the efficiency levels noted in Figures 4-1 through 4-9. The

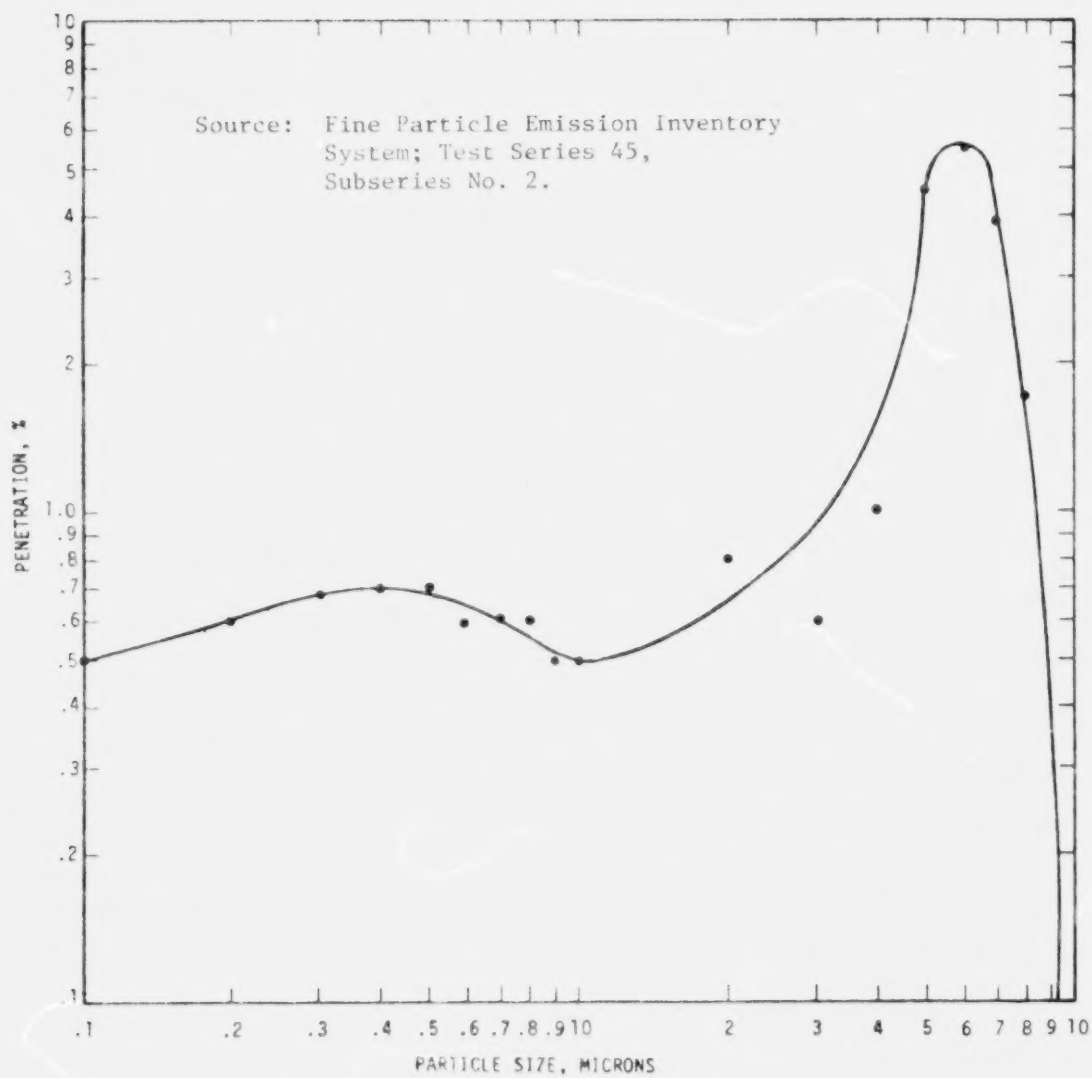


Figure 4-10. Fractional efficiency curve for an electrostatic precipitator serving seven open hearth furnaces.

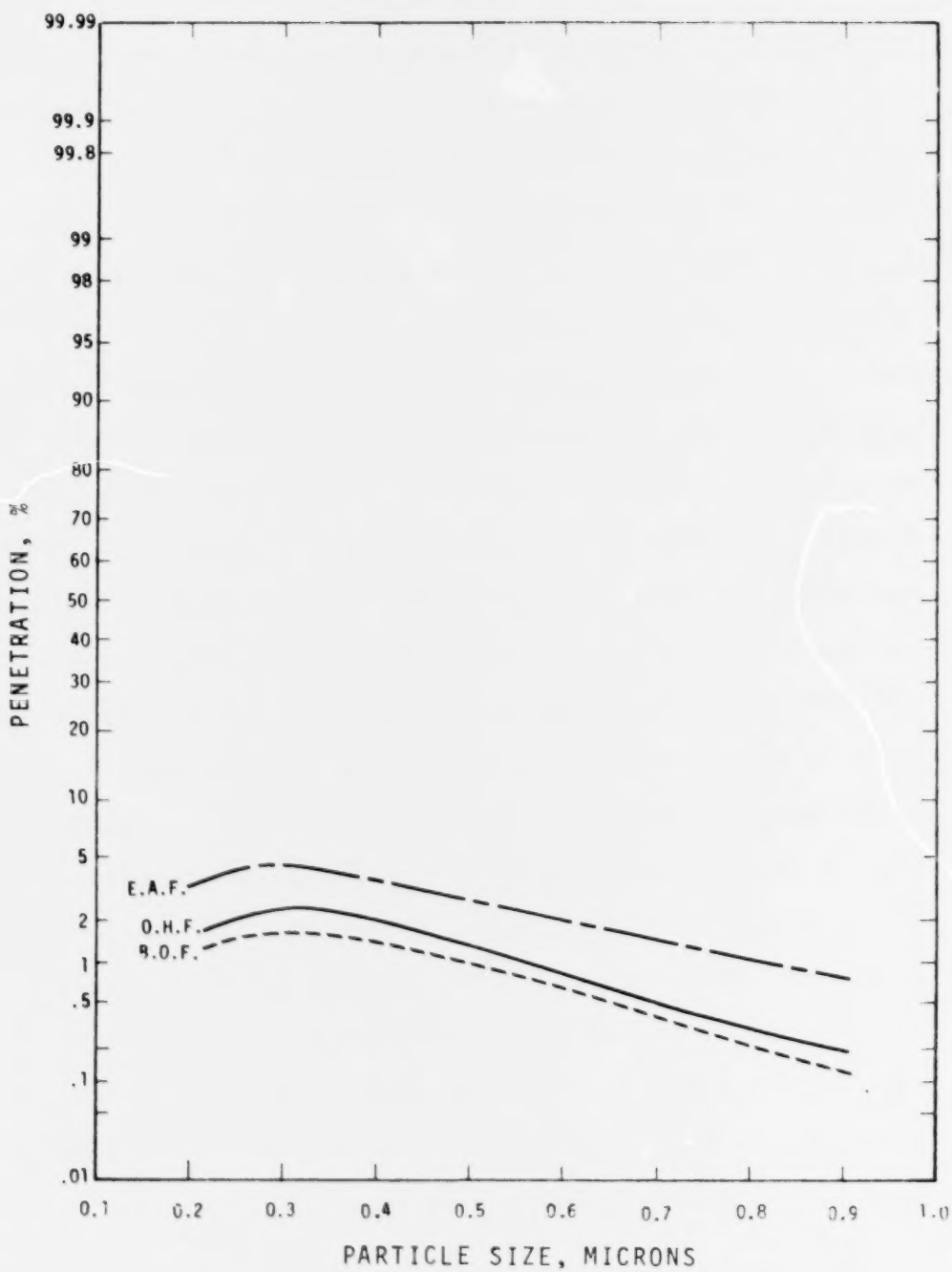


Figure 4-11. Percent penetration predicted versus particle size for 99.0 percent overall mass collection efficiency.

efficiencies are shown to range from 95.0 to 99.9 for all applications. This was done to provide continuity with the performance comparison of the applications at comparable efficiency levels. In practice, the efficiencies normally attainable or required to meet emission standards will depend on the process and site, and they may vary substantially within the 95.0 to 99.9 percent efficiency range.

4.2.2 Venturi Scrubber Computer Models

4.2.2.1 Design Equations and Assumptions - Research Cottrell Model - Venturi scrubbers are well described in the available literature.^{3,4} The particle collection process depends mainly upon the acceleration of the gas to provide impaction and intimate contact between the particles and fine liquid droplets generated as a result of atomization by the high velocity gas. The other factor which plays an important role in the effectiveness of the venturi scrubber is the condensation effect. If the gas in the reduced pressure region in the throat is fully saturated, condensation will occur on the particles in the higher pressure region of the diffuser. This is known as heterogeneous nucleation, an effect which helps particle growth and also causes agglomeration which tends to enhance collection. The detailed particle collection mechanisms in the venturi scrubber have been investigated by many researchers.^{4,5,6}

The venturi model used in this study is based on inertial impaction. The general form of the expression for the collection efficiency of the i^{th} particle size can be written as

$$E_i = 1 - \exp(-KL \Psi_i) \quad (1)$$

where E_i = Fractional collection efficiency of particle size

K = System parameter

L = Liquid-to-gas ratio

Ψ_i = Inertial impaction parameter of particle size i .

Available experimental data have been used to develop a correlation for inlet throat velocity, V_t in ft/s, based on ΔP (in. H_2O) and outlet L/G measurements.

$$V_t = \frac{\Delta P^{1/2}}{5.23 \times 10^{-6} (L/G + 105)} \quad (2)$$

Knowing the inlet throat velocity and measured outlet L/G , the droplet diameter in microns can be calculated from a modified form of an equation developed by Nukiyama and Tanasawa.⁷

$$D_c = \frac{16050}{V_t} + 1.41 (L/G)^{1.5} \quad (3)$$

The system parameter K is determined by an iterative procedure based on comparison of the actual measured overall mass collection efficiency and that calculated from summing the individual fractional efficiencies. For a given particle size the inertial impaction parameter is defined below:

$$\psi_i = \frac{0.85 (C) (\rho_p) (D_p)^2 v_t}{\mu D_c} \quad (4)$$

where C = Cunningham correction coefficient

ρ_p = Particle specific gravity, (grams/cm³)

D_p = Particle diameter, (microns)

μ = Dynamic gas viscosity, (poise x 10⁴)

D_c = Droplet diameter, (microns)

$$\text{and } C = 1 + \frac{2\lambda}{D_p} \left[1.23 + 0.41 \exp(-0.44 \frac{D_p}{\lambda}) \right] \quad (5)$$

where λ = Mean free path of gas molecules, (microns)

The value of K is modified during the course of iteration to yield a closer match between measured and calculated overall mass collection efficiencies for given input values of L/G and ΔP . When the "optimum" value of K has been found, it is inserted into the above equations to generate the outlet particle size distribution and finally the fractional penetration for the various particle sizes. It should be noted that this is really an averaged system parameter since it is not a function of any specific particle size.

4.2.2.2 Design Equations and Assumptions Calvert Model⁴ -

PEDCo used Calvert's Model to compare its results to those generated by the Research Cottrell Model. Design equations for Calvert's Model can be found in reference 4. In addition to the inertial impaction mechanism, an equation for

collection by Brownian motion developed by Yung et. al.⁸ was included in the evaluation. An "f" factor of 0.5 was assumed for all test runs.

4.2.2.3 Penetration as a Function of Particle Size - Both the RC model and Calvert's model were used to predict penetration as a function of particle size for the applications of open hearth, electric arc, basic oxygen, and ferroalloy furnaces, and sintering. Results of the Research Cottrell model are presented in Appendix D-1. Similar results were obtained by PEDCo using Calvert's model. In contrast to Research Cottrell's model, Calvert's model showed higher penetrations in the lower size ranges, but a sharper decrease in penetration as the particle size increased. Predicted overall mass efficiencies tended to be lower with Calvert's model.

These results indicate that the particle size distribution used as inputs for the steelmaking and ferroalloy arc furnaces, are outside the limits for which the models were designed. Information in the literature indicates that with pressure drops of 40 to 80 inches of water, a venturi scrubber on a BOF, open hearth, or steel/ferroalloy arc furnace, should have overall mass efficiencies in the range of 95 to 99.5 percent. Both models predict substantially less overall efficiency.

One reason for the inability of the models to predict the expected high overall efficiencies is that other mechanisms which could increase the collection efficiency of fine particles, such as heterogeneous nucleation, electrostatic effects, or thermophoresis are not included in either the RC or Calvert's model. It was found that Brownian motion in Calvert's model had no significant effect on the overall collection efficiency presumably due to the high gas velocities being used (150-250 ft/s). Inertial impaction as a collection mechanism is only significant down to a particle size of around $0.5 \mu\text{m}$. Since the mass median diameters for the steel making furnaces were all below $1 \mu\text{m}$, use of both these models, which rely heavily on inertial impaction as a collection mechanism, is actually an extrapolation below the range of particle sizes for which both models are designed to operate most efficiently. The predictions for the sintering process with and without a mechanical collector by contrast, show that with a larger particle size distribution, (for example, sintering preceded by mechanical collector, $\bar{x} = 7$, $\sigma_g = 35$) the models predict efficiencies well in excess of 99 percent with pressure drops of 1) 35 to 70 inches of water with the RC model, and 2) 20 to 30 inches of water for Calvert's Model.

Fractional efficiency test data are available for a venturi scrubber on a silico-manganese ferroalloy furnace in Nikopol, Russia.⁹ The venturi scrubber is preceded by 1) an inclined gas line (500-mm diameter) into which water is sprayed, and 2) a 1000-mm diameter spray chamber which contacts the gas counter currently. Average particulate inlet concentrations into the scrubber are 5.19 g/Nm^3 ; outlet concentrations are 5.94 mg/Nm^3 , with an average efficiency of 99.89 percent.

The particulate size of the fumes was initially small; substantially less than $1 \text{ }\mu\text{m}$.⁹ However, the particles would agglomerate and increase the mass median diameter to as high as $3 \text{ }\mu\text{m}$. Results of particulate sizing data gave a log normal size distribution with an average mass median diameter at the inlet to the scrubber of $1.7 \text{ }\mu\text{m}$ with a geometric standard deviation (σ_g) of approximately 2.⁹

A comparison of actual test results and predicted penetration as a function of particle size using Calvert's model,⁴ is presented in Figure 4-12. Predicted and actual penetrations are in agreement at a particle size of $0.3 \text{ }\mu\text{m}$. However, for particle sizes larger than $0.3 \text{ }\mu\text{m}$, the predicted penetration decreases more rapidly than does the actual penetration.

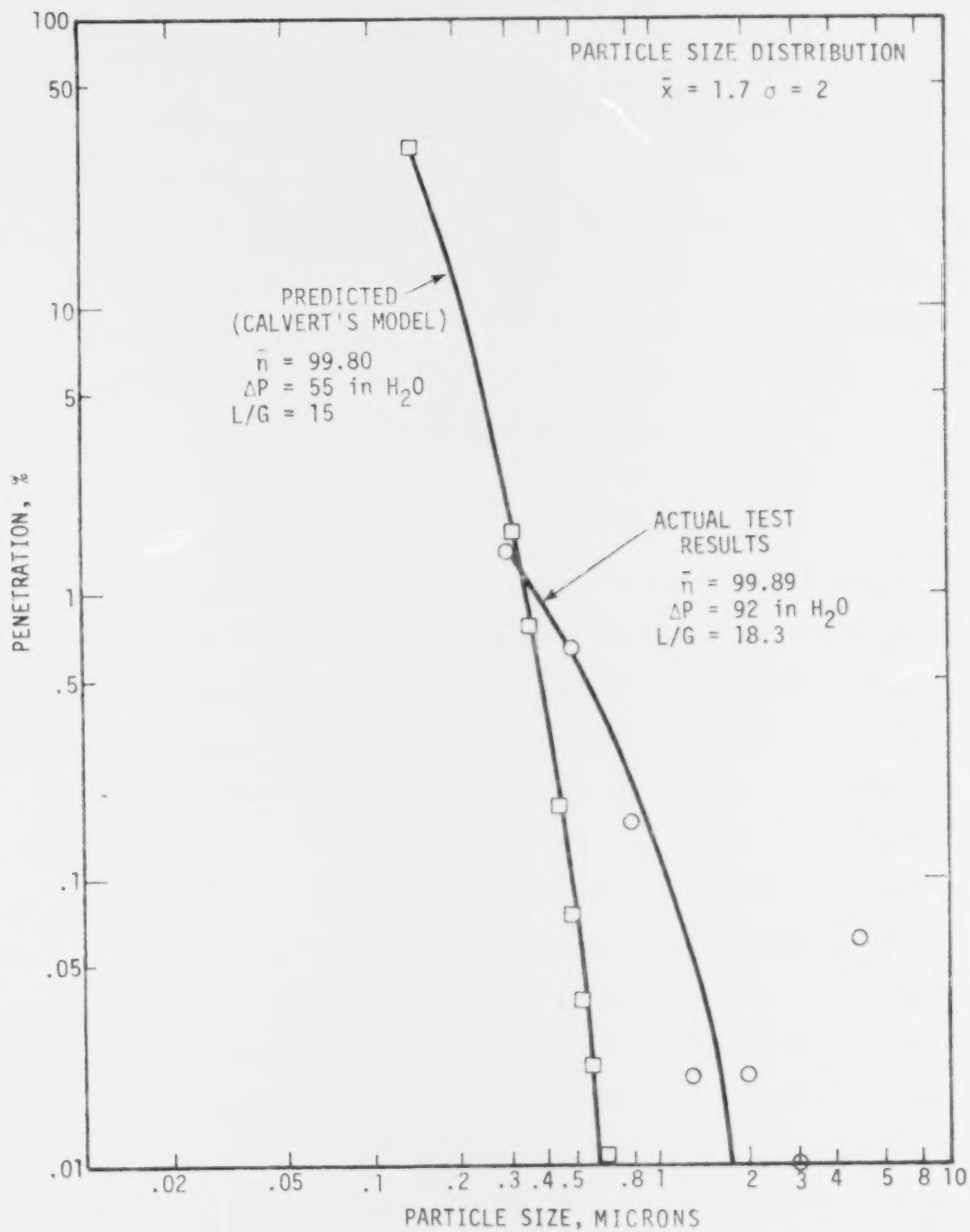


Figure 4-12. Predicted and actual performance of the Nikopal venturi scrubber on a ferroalloy furnace.

Unfortunately, additional scrubber test data on the steel/ferroalloy processes covered in this report are not available for comparison with the models.

4.3 FRACTIONAL EFFICIENCY RELATIONSHIPS FOR WET ESP'S

A mathematical model was not utilized to predict the efficiency of a wet precipitator as a function of particle size for the iron and steel processes covered in this report. Southern Research Institute¹⁰ has used a mathematical model to compare predicted efficiencies with test results on an aluminum reduction pot line (see Figure 4-13). They found that the model under predicted fine particle collection efficiencies less than 0.6 μm , and over predicted efficiencies greater than 0.6 μm .

The wet ESP test results from the aluminum reduction pot line¹⁰ show uniform high collection efficiency in the particle size range of 0.05 to 10.0 μm . These results also do not show a reduction in efficiency in the 0.2 to 0.4 μm size range, which is characteristic of dry ESP's, due to the transition from field charging to diffusion for collection of fine particles. Since reentrainment is kept to a minimum in a wet precipitator, Figure 4-13 does not show an increase in emissions at 6 to 7 μm , which is characteristic of dry ESP's, resulting from agglomeration of small particles and subsequent reentrainment.

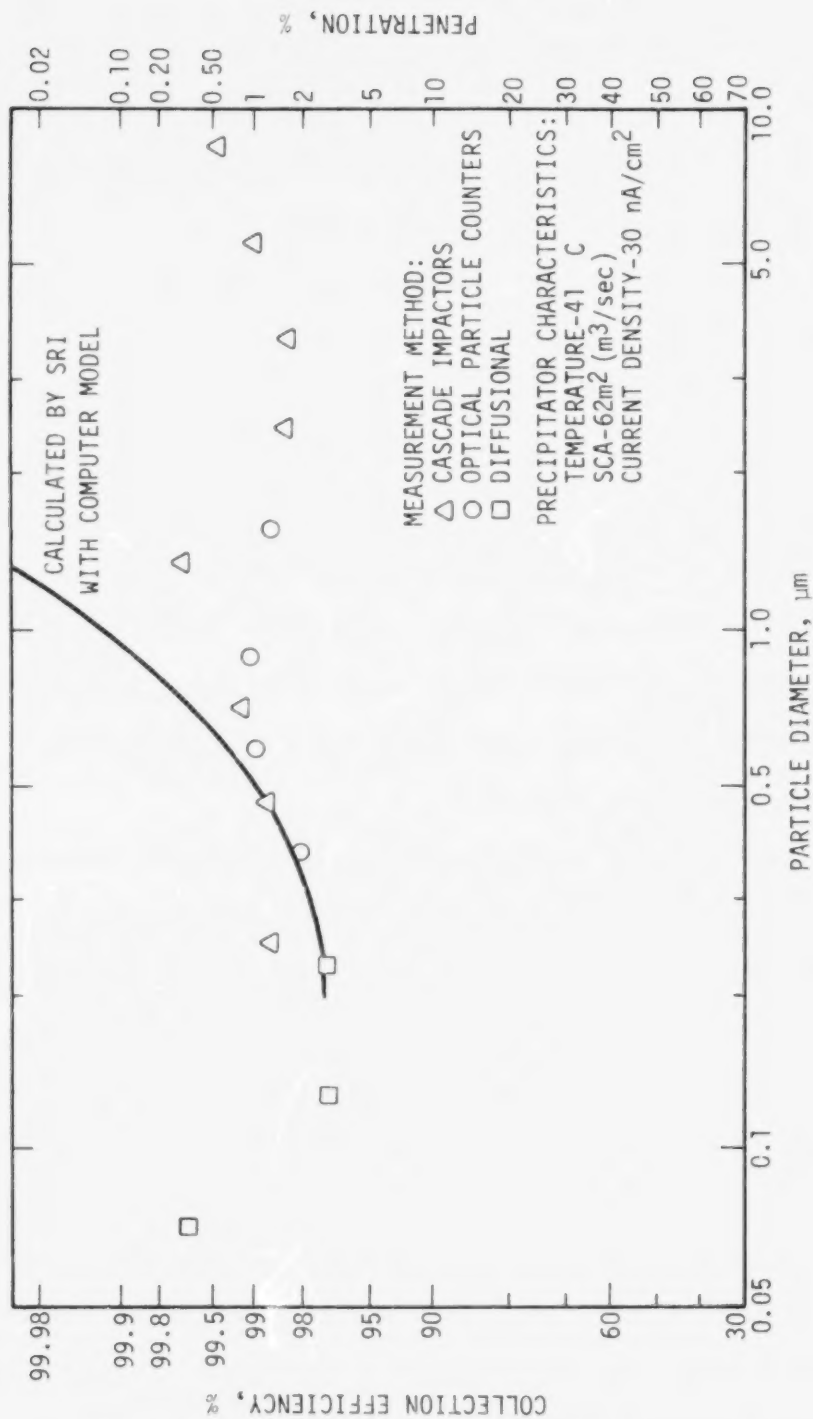


Figure 4-13. Measured and predicted efficiencies for a wet precipitator installed downstream of a spray type scrubber on an aluminum reduction pot line.¹⁰

Since no fractional efficiency test results are available for wet precipitators on steel/ferroalloy processes, it is not certain that similar fractional efficiency performance to that shown on aluminum reduction potlines could be expected. Overall efficiencies from pilot tests of two types of wet ESP's on scarfing fumes ranged from 87.20 to 99.43 percent.¹¹ Full-scale tests of a wet ESP on a sinter plant showed overall mass efficiencies ranging from 96.20 to 98.75 percent, under various conditions. However, collection of condensable hydrocarbons did not exceed 50 percent.¹¹ Pilot scale tests on the same sinter plant showed a range of 50 to 93.75 percent, for collection of condensable hydrocarbons.¹¹

Since the operation of a wet precipitator is not influenced by the resistivity of the dust layer, the dielectric constant of the particle material and its size are the two most important particle parameters. Particles with a dielectric constant of less than 10 are much more difficult to collect than conductive particles, and fine particles, of course, are the most difficult to collect; however, wet precipitators with three fields have reportedly shown overall mass collection efficiencies on solid particles of greater than 99.5 percent even if 80 percent of the particles were less than one μm in size.¹² Removal efficiencies

higher than 95 percent have been measured on condensable hydrocarbons (tar fumes).¹²

4.4 FRACTIONAL EFFICIENCY RELATIONSHIPS FOR FABRIC FILTERS

It would be desirable to characterize baghouse collection efficiency as a function of particle size for each of the processes discussed. However, manufacturers are reluctant to base baghouse guarantees on fractional collection efficiency. They prefer overall collection efficiency or outlet concentration guarantees based on their past experience with the same or a similar type of process. There is little incentive for manufacturers to relate baghouse performance to particle size on existing systems and as a result, this information is practically nonexistent. Even though fractional efficiency data for baghouses in the iron and steel industry are lacking, there is adequate evidence in the literature from other industries to document the fact that fabric filters preserve good fractional efficiency down to and through the submicron particle range. In other words, unlike scrubbers and ESP's, fabric filters preserve high collection efficiency for the small particle size ranges without any modification to their design or operation. It must be pointed out, however, that there are several subtleties reported in the literature regarding the actual shape of the fractional efficiency curve for a fabric filter. These are briefly discussed here.

There are reports suggesting that the collection efficiency of a fabric filter tends to drop somewhat in the sub-micron particle size range, particularly in the 0.2 to 0.4 micron region. This behavior is also common to scrubbers and ESP's except that in their case the drop in efficiency is more pronounced. In one recent report*, it is postulated that mechanisms during high velocity filtration can actually lead to decreased filtration efficiency on larger particles. The three mechanisms are as follows:

1. Straight Through Penetration: Immediately after cleaning, many particles collect upon the exposed fibers. Soon, however, a continuous dust deposit forms on the fabric surface and particles collect upon previously deposited dust. Particles not collected by the filter, but which pass through without stopping penetrate the filter by the "straight through" mechanism.

2. Seepage: Once a particle lands on or in the fabric, it need not necessarily remain at its point of initial impact. As the dust deposit builds up, pressure drop can increase to several times its initial value. Meanwhile, the fabric substrate may stretch, allowing some previously collected particles to work through. Filter behavior of this sort is "seepage."

* Leith, D., et al. High Velocity High Efficiency Aerosol Filtration, EPA - 600/2-76-020, January 1976.

3. Pinhole Plug: Small diameter pinholes occur at the surface of dust deposit on woven fabrics. Similar holes on a needle-punched felt may correspond to the places where needles penetrated the cloth during its manufacture. A plug of deposited particles may dislodge from the dust deposit and pass through the fabric all at once as the supporting fibers move and stretch beneath it, leaving behind such a pinhole. Particles which pass through the filter in this way do so by a "pinhole plug" mechanism.

Therefore, particles can pass through the filter by the "straight through" mechanism, without being stopped, whereas previously collected particles can make their way through by the "seepage" and "pinhole plug" mechanism. In addition, the fraction of the total fabric filter penetration represented by "pinhole plugs" can be as high as 70 percent. This could account for the presence of large particles on the outlet side of baghouses in amounts not expected by considering classical filtration theory.

None of the respondents to the questionnaire survey used in this study could provide reliable fractional efficiency information, and only one could provide particle size information on the baghouse inlet and outlet. This information is presented in Figure 4-14. One fractional efficiency test of a baghouse on two electric arc furnaces was obtained from the literature.¹³

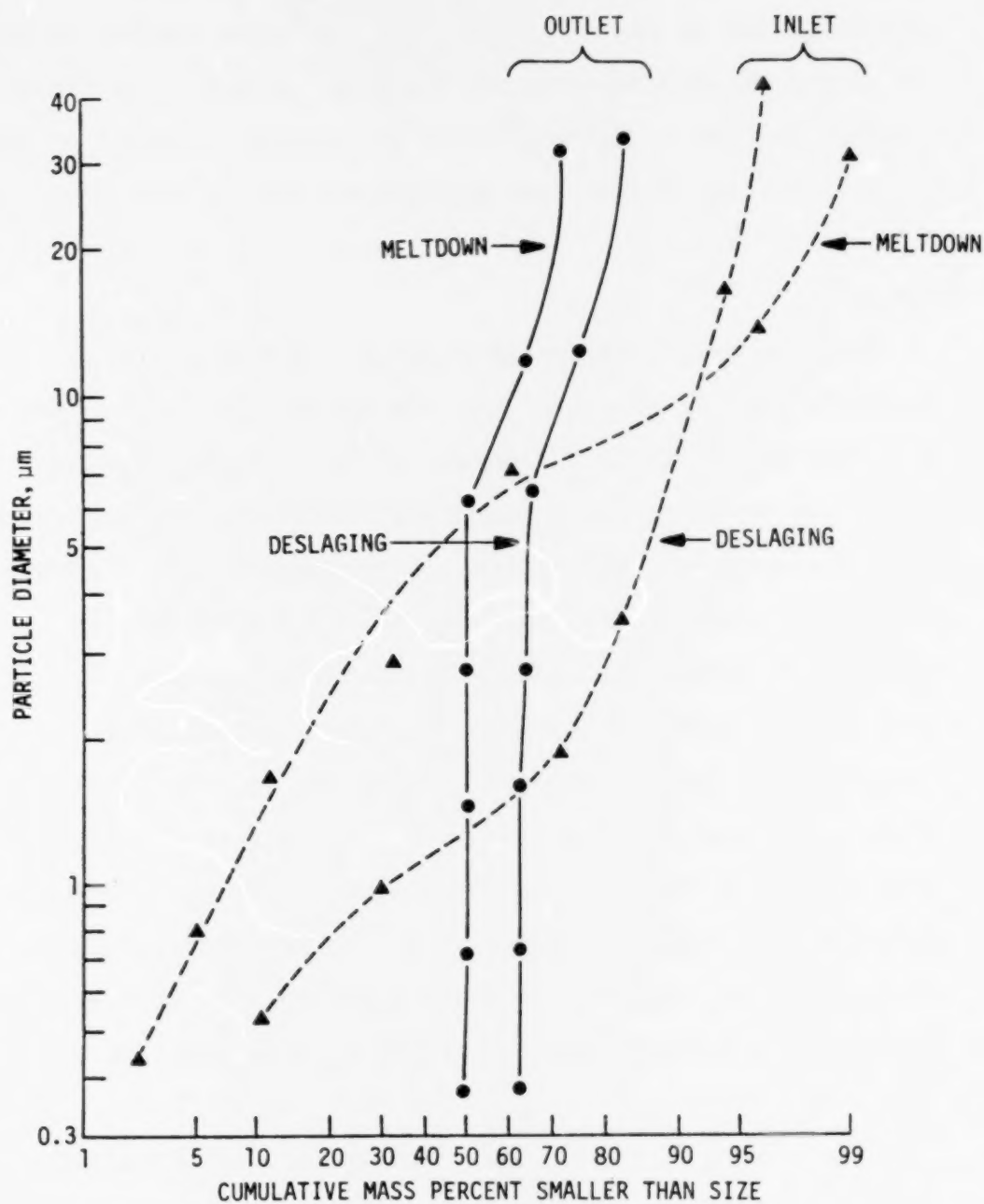


Figure 4-14. Particle size distributions of electric arc furnace dust at inlet and outlet of baghouse.

The particle size distribution data in Figure 4-14 were obtained as part of an overall baghouse testing program which established the average baghouse collection efficiency at 94.5 percent. This result is considered atypical of baghouse performance for this application and is probably indicative of ruptured bags, broken welds in the cell plate, etc.

Figure 4-15 presents penetration as a function of particle size (1 - 10 μm) for a baghouse operating on two electric arc furnaces.¹³ These curves show that 1.0 μm particles have the least penetration while 6.0 μm particles have the greatest penetration, contrary to fabric filtration theory. These results indicated that agglomeration of smaller particles was occurring, mainly as a result of fabric rear face dislodgement of collected particles. A comparison of inlet and outlet differential size distributions suggested that because of their similarity in shape, some of the influent aerosol was passing through the baghouse without capture, indicating bag leakage during sampling. Average overall mass efficiencies were 97.9 percent with one furnace operating and 98.7 percent with two furnaces operating.

In summary, a wide variety of factors (inlet grain loading, air-to-cloth ratio, type of cleaning employed, dust

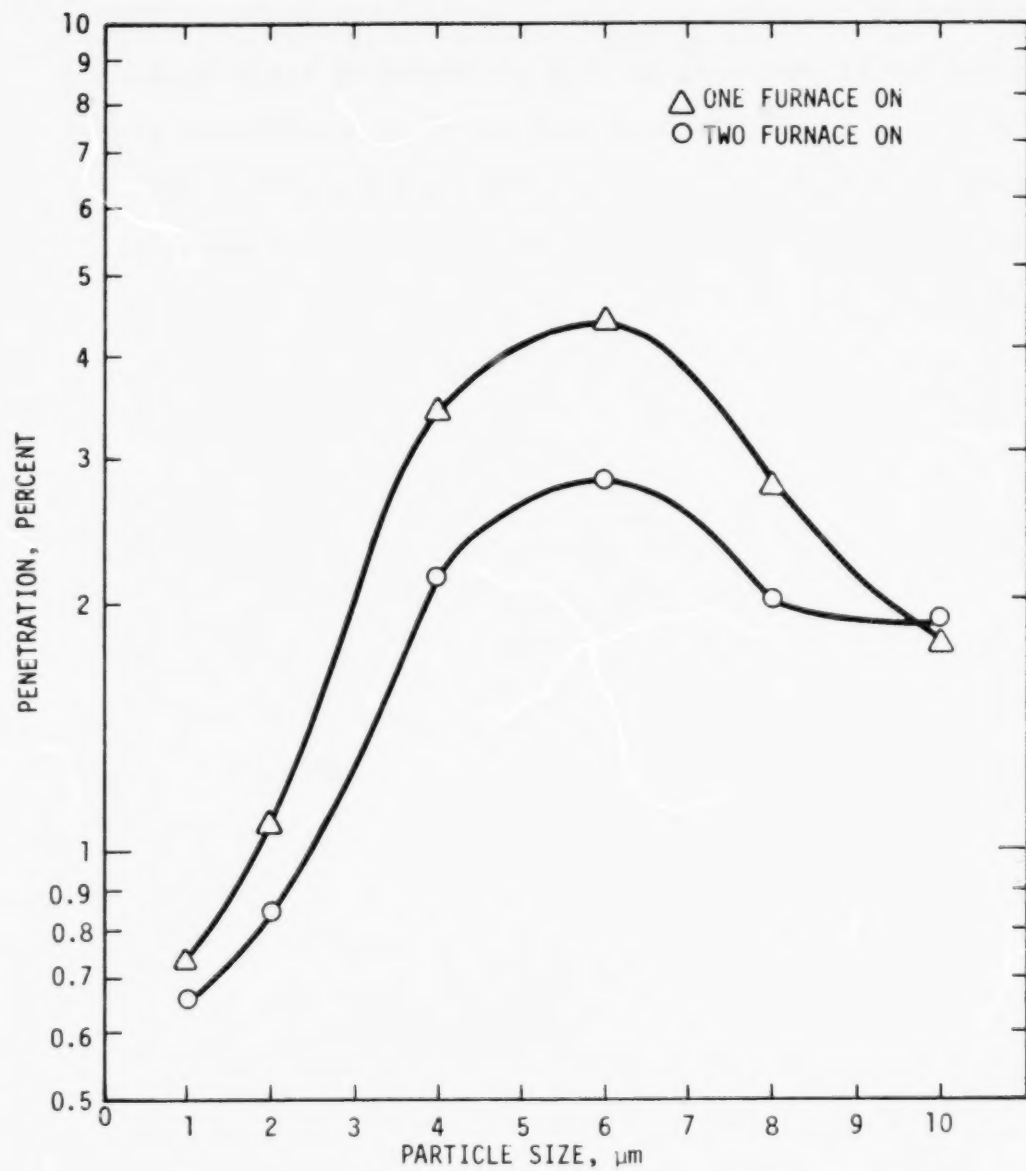


Figure 4-15. Fabric filter fractional penetration curves.¹³

characteristics, etc.) can affect particle penetration, and current understanding has not advanced to the point where one can conclusively predict expected penetration as a function of particle size for a particular source. This difficulty is enhanced by lack of measured field data. At this point, it can only be said that the fractional efficiency of a fabric filter is normally high (99+%) and that there is little reduction of efficiency in the submicron region.

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5.0 SUMMARY AND CONCLUSIONS

This report has reviewed the use of conventional control devices (dry/wet ESP's, scrubbers, and fabric filters) for limiting particulate emissions from electric arc, basic oxygen, open hearth and ferroalloy arc furnaces, and sintering and scarfing processes in the steel and ferroalloy industries. Important design parameters, operation and maintenance procedures, and the fractional efficiency capability of each control device were the areas of study. The following sections present conclusions drawn from each area of study.

5.1 DESIGN PARAMETERS

It is evident from study of the steel/ferroalloy processes included in this report that there is much wider use of scrubbers, fabric filters and wet ESP's, as opposed to the use of dry ESP's as is the case almost exclusively in the utility industry. Many times, the characteristics of the process dictate the choice of a control device. Tables 5-1 through 5-4, however, present general advantages of the four types of control devices considered in this report, as applied to the steel/ferroalloy processes studied. Table 5-5

Table 5-1. ADVANTAGES AND DISADVANTAGES OF USING DRY PRECIPITATORS
ON /FERROALLOY PROCESSES

Control device	Advantages	Disadvantages
Electrostatic precipitator	1) Can be designed to provide high collection efficiency for all sizes of particles from submicron to the largest present; new designs can meet stringent particulate regulations. 2) Economical in operation because of low internal power requirements and inherently low draft loss; high reliability. 3) Flexible in gas temperature used, ranging from as low as 125°F to as high as 800°F. 4) Long useful life, if properly maintained. 5) No water pollution potential. 6) Extensive history of application.	1) High resistivity of process dust degrades performance of cold precipitator not designed for this type of fuel. 2) Insulator tracking, discharge wire breakage; ash hopper plugging and corrosion are potential maintenance problems. 3) Efficiency is sensitive to change in dust characteristics. 4) Potential explosion and fire problems during start-up because of high voltage sparking. 5) High-voltage hazards to personnel.

Table 5-2. ADVANTAGES AND DISADVANTAGES OF USING WET SCRUBBERS
ON STEEL/FERROALLOY PROCESSES

Control device	Advantages	Disadvantages
Wet scrubber	1) Smaller space requirements than precipitator or fabric filter. 2) Not affected by high resistivity process dust; relatively insensitive to chemical composition and variations in gas temperature. 3) No high-voltage hazard.	1) Collection efficiency decreases rapidly with decreasing particle size. 2) Maintenance costs are higher than for precipitators and fabric filters. (Corrosion, scaling, plugging) 3) Water pollution control required for scrubber effluent. 4) Very high pressure drop and resulting higher power demand needed for high efficiency.

Table 5-3. ADVANTAGES AND DISADVANTAGES OF USING FABRIC FILTERS
ON STEEL/FERROALLOY PROCESSES

Control device	Advantages	Disadvantages
Fabric filter	1) Collection efficiency essentially independent of chemical content in dust. 2) High overall mass and fractional efficiency. (99+%) 3) Collection efficiency and pressure drop are relatively unaffected by changes in inlet grain loadings for continuously cleaned filters. 4) No water pollution potential. 5) Corrosion is not a problem, with bags. 6) No high-voltage hazard, thus simplifying repairs.	1) Higher pressure drop than ESP resulting in higher energy consumption. 2) Fabric life is difficult to estimate; may be shortened in the presence of acid or alkaline particles, fluorides. 3) Space requirements are usually greater than for precipitators or scrubbers, except at high air-to-cloth ratios. 4) Condensation of moisture may cause crusty deposits or plugging of the fabric or require special additives.

Table 5-4. ADVANTAGES AND DISADVANTAGES OF USING
WET PRECIPITATORS ON STEEL/FERROALLOY PROCESSES

Control device	Advantages	Disadvantages
Wet Precipitator	1) Eliminates resistivity problems through the moisture conditioning effect minimizes reentrainment. 2) Enhances collection through the condensation nucleation effect of fine particles. 3) Eliminates cleaning (rapping losses, since no rapping mechanism is required). 4) Has a low pressure drop typical of dry ESP's.	1) High potential for corrosion and scaling. 2) Loss of plume buoyancy. 3) Requires water treatment system. Spray nozzles subject to plugging if water treatment system malfunctions. 4) Has not been proved advantageous on a large scale basis for many applications.

Table 5-5. SUMMARY OF USAGE OF VARIOUS CONTROL DEVICES ON
SELECTED STEEL/FERROALLOY PROCESSES^a

Process	Number of plants which list control device used	Number of each control device used ^b			
		Dry ESP	Wet ESP	Wet Scrubber	Fabric Filter
Steel Electric Arc Furnace	70	2	-	4	64
Basic Oxygen Furnace	37	18	-	19	-
Open Hearth Furnace	13	12	-	1	-
Ferroalloy Arc Furnace	13	1	-	5	7
Sintering					
windbox discharge	18 5	7 ^c -	- -	10 2	2 3
Scarfig	39	7	12	12	7

^a See Appendix A for available listing for each process.

^b May exceed total since some installations use more than one control device.

^c Does not differentiate between dry and wet ESP's.

presents an estimate of the extent of use of the control devices on each process covered.

5.1.1 Dry precipitators

Dry precipitators are used frequently on sintering windboxes, open hearth, and basic oxygen furnaces, and occasionally on electric arc and open ferroalloy furnaces and scarfing process.

The basic unit used for sizing the specific collecting area (SCA) was presented a function of collection efficiency instead of sulfur or iron and sodium content of coal, as is the case in the coal fired utility industry. Resistivity of the process dust, however, is still the main governing factor that influences the SCA. The correlational graphs shown in section 2.0 for dry ESP's, indicate that the SCA requirements for the steel/ferroalloy processes are not as high as those required for low-sulfur coal in the coal fired utility industry. Dry precipitators for the sintering process have the highest SCA requirements, followed by the electric arc furnace, scarfing, open hearth furnace, and basic oxygen furnaces.

5.1.2 Wet ESP's

Wet ESP's are being used on steel/ferroalloy processes such as scarfing and sintering where other control devices have performed unsatisfactorily. Since the performance and

collection efficiency of the wet ESP are not dependent on the resistivity of the dust layer, the two most important particle parameters are its size and dielectric constant.

The basic method of designing wet ESP's has been by analogy based on empirical application of the Deutsch equation, which does not account for changes in particle size distribution as gas moves through the precipitator. Recently some pilot plant studies have been conducted, but very little design data could be obtained either from the literature or from vendors. Perhaps the design procedure could benefit from application of some modification of the Deutsch equation, such as use of the Matts-Öhnfeldt modified migration velocity.¹

Since almost no design data were obtained, no specific correlations could be developed for the application of wet ESP's to the steel/ferroalloy processes studied. Organic condensable materials from steel/ferroalloy processes are likely to be the most difficult to collect, since they usually have a low dielectric constant.

5.1.3 Venturi scrubbers

Venturi scrubbers are used frequently on semienclosed and sealed ferroalloy furnaces, basic oxygen furnaces, in some instances on the wind box and discharge end of sintering plants, and on open hearth and electric arc furnaces.

One of the problems with using a venturi scrubber for these steel/ferroalloy applications is the high pressure drop (60-80 in. H_2O) and subsequent high energy use, required to meet particulate emission regulations. The key design parameters that affect particulate collection are the same as for other applications, i.e., gas velocities/flow rates, particle size distribution, pressure drop and liquid to gas (L/G) ratio.

In developing correlations for the venturi scrubber, a problem arose because most of the particle size distributions for the steel/ferroalloy processes studied are too small for either the Research Cottrell model or Calvert's model. Therefore, the overall collection efficiencies obtained were not high enough for the energy being expended. However, in general, the correlations showed a strong effect of pressure drop on collection efficiency with L/G ratio showing no great effect.

5.1.4 Fabric filters

Fabric filtration is the preferred technique for steel and open ferroalloy arc furnaces; it is used fairly often on the discharge end or sinter strands and occasionally on sinter windboxes. Use of fabric filters and ESP's on sinter windboxes could be a developing market. Some ferroalloy producers design their own equipment, including baghouse and

forced convection gas cooling, both of which seem to perform well in the field.

In general, the design of fabric filters does not differ substantially from application to application for the same cleaning mechanism. This is because baghouses are relatively insensitive to process variables such as chemical composition, particle size, and resistivity, although fabric selection can be critical with respect to the chemical composition of particles. Some installations in the steel/ferroalloy industry use pulse jet cleaning, which differs from the reverse air and shaker methods. Pulse jet cleaning allows higher air-to-cloth ratios to be used because cleaning is done during operation and less space is required for the fabric filter. However, most baghouses and peripheral equipment are almost the same physical size as the process itself. This makes the space requirement extremely large and the total system very costly. Current research in fabrics and filtration technology could reduce both the size and cost of fabric filtration systems.

5.2 OPERATION AND MAINTENANCE

In comparing operation and maintenance problems of particulate control devices on steel/ferroalloy processes to the coal fired utility industry, one finds many parallels and some differences.

For dry and wet ESP's corrosion is a major problem contributing to the loss in efficiency. High voltage tracking on the insulators in dry ESP's as a result of the formation of condensables in insulator compartments is also a problem. Strict pH control must be maintained on re-circulated water for wet ESP's to minimize corrosion or scaling and plugging of spray nozzles.

Wet scrubber problems in the steel/ferroalloy industry are similar to those identified for utility applications: plugging, scaling, and corrosion. Inspection and maintenance procedures are very similar for utility and steel/ferroalloy applications.

Likewise, for fabric filters, maintenance procedures for steel/ferroalloy applications are similar to those for utilities. Start-up and shutdown of a fabric filter are extremely critical since unexpected temperature, pressure, or moisture during start-up can badly damage bags in a new installation. Condensation is the main problem associated with the shutdown procedure. Bag replacement is the most expensive maintenance operation, and other characteristic maintenance problems center around dampers and screw conveyors for hoppers and shaker linkages.

For all control devices, no data are available on the effect of control device malfunctions on fractional efficiency performance, although it will degrade faster than the overall mass efficiency, especially in the fine particle range. This is an area where further study could be directed, in anticipation of standards for performance for particulate control devices, based on particle size in addition to overall mass efficiency.

5.3 FRACTIONAL EFFICIENCY RELATIONSHIPS

Models for predicting performance as a function of particle size were presented for dry ESP's and venturi scrubbers.

The computer model for dry ESP's showed the same characteristic increase in penetration in the 0.2 to 0.5 μm size range due to the transition region between field charging and diffusion as collection mechanisms. Only one test result was available to confirm the model, that of an ESP treating off gas from seven open hearth furnaces. The test data showed an increase in penetration at about 0.4 μm and another increase at 6 μm , presumably because of agglomeration and reentrainment of smaller particles.

Two different computer models were tested for the wet scrubber applications. Research Cottrell used their model and PEDCO used Calvert's model² for the evaluation. Both

models rely on inertial impaction as the collection mechanism and both models did not predict high enough overall and subsequently fractional efficiency at the pressure drops being used ($\approx$ 40 to 80 in. H_2O). PEDCo incorporated an equation into Calvert's model for Brownian diffusion³, but found that it had a minimal effect on efficiency, presumably because of the high gas velocities used (150 to 250 ft/sec). It was concluded that the particle size distributions for the steel/ferroalloy furnaces were too small and thus out of the range for which the models were designed. Reasonable results were obtained for the performance predictions for the sintering process. Inclusion of additional collection mechanisms, such as diffusiophoresis, thermophoresis, and electrostatic effects, were considered beyond the scope of the project.

Test results from a venturi scrubber on a ferroalloy furnace in Russia⁴ were compared with Calvert's model, and reasonable agreement was obtained. The test results showed very high overall and fractional efficiencies (99.89% overall) at very high pressure drops (88 to 94 in. H_2O).

A fractional efficiency prediction model was not utilized in evaluating the fractional efficiency performance of wet ESP's on steel/ferroalloy processes. Wet ESP's have shown excellent collection of solid particulates (>99.5%)

even when 80 percent of the particles are less than 1 μm in diameter.⁵ Removal efficiencies of 95 percent and higher have been reported for condensible hydrocarbons.⁵ However, no fractional efficiency test data are available to verify this type of performance for the steel/ferroalloy processes evaluated in this report.

A fractional efficiency prediction model was not available for use in evaluating fabric filter performance. Although fractional efficiency test data are likewise not available, there is evidence in the literature from other industries to indicate that fabric filters preserve high fractional efficiency (>99%) down to and through the sub-micron range. An increase in penetration is observed in the 0.2 to 0.4 μm size range, although it is not as pronounced as with ESP's and scrubbers; Leith, et al. in one recent report⁶ postulated collection mechanisms which during high velocity filtration actually lead to a decrease in efficiency at larger particle sizes. However, given the lack of test data and a proper prediction model, it can only be said with reference to the steel/ferroalloy industry, that the fractional efficiency of a fabric filter is normally high (99%+) with little reduction in efficiency in the submicron particle range.

The evaluation of the fractional efficiency relationships for all the control devices brought out two important facts. One is the limited, scattered, and conflicting particle size data available, pointing out the need for a reliable, consistent, and widely used technique for measuring particle size distribution. Valuable data could then be collected on various steel/ferroalloy applications under different operating conditions. Second is the lack of fractional efficiency test data on dry and wet ESP's, wet scrubbers, and fabric filters for the steel/ferroalloy applications under consideration. This type of test data is needed to characterize the performance of each control device, is helpful in establishing and verifying fractional efficiency prediction models, and would be essential to developing accurate fine particulate emission standards in the future.

5.4 COSTS

A model was not used to compare the costs of various control devices on the various steel/ferroalloy processes considered. Literature sources were used in the cost examples for wet ESP's and fabric filters. In-house costs from Research Cottrell and PEDCo were used to estimate costs for wet scrubbers and dry ESP's, respectively. For wet scrubbers, the costs are based on the efficiencies generated

by the Research Cottrell wet scrubber performance model, which as discussed previously does not predict high enough efficiencies at the pressure drops used as input. These costs, therefore, are somewhat lower than could be expected at higher collection efficiencies. However, it is important to note that this cost information is very useful in a relative sense, irrespective of problems encountered with particle size distribution/performance model combinations.

Since the cost estimates for each control device are not on the same basis, no conclusions are drawn with regard comparison of cost for various control devices on the same process.

REFERENCES FOR SECTION 5.0

1. Matts, S. and P.O. Öhnfeldt, "Efficient Gas Cleaning with S.F. Precipitators."
2. Wet Scrubber Systems Study, Vol. I, Scrubber Handbook, A.P.T. Inc., PB 213-016, July 1972.
3. Drechsel, Dennis C., "Field Test of a Venturi Scrubber in Russia," presented at the 2nd EPA Fine Particle Scrubber Symposium, EPA-600/2-77-193, New Orleans, Louisiana, May 2-3, 1977.
4. Bakke, E., Mikropul Division of U.S. Filter Corporation, "Application of Wet Electrostatic Precipitator for Control of Fine Particulate Matter," presented at the Symposium on Control of Fine Particulate Emissions From Industrial Sources, Dallas, Texas, January 15-18, 1974.
5. Leith, D., et al., "High Velocity High Efficiency Aerosol Filtration," EPA-600/2-76-020, January, 1976.

APPENDIX A

INSTALLATION LISTS FOR SELECTED STEEL/FERROALLOY PROCESSES

APPENDIX A-1.

SINTER RECLAMATION PLANTS IN THE U.S. INTEGRATED IRON AND STEEL INDUSTRY^a

Company	Location	No. of strands	Estimated annual capacity, net tons	Ignition fuel	Machine windbox	Machine discharge	Crushing & screening
Alan Wood Steel Co.	Swedeland, Pa.	3	475,000	Coke oven gas	Scrubber	Baghouse	Scrubber
Bethlehem Steel Corp.	Johnstown, Pa.	2	1,100,000	Natural gas	ESP	Scrubber	Scrubber
U.S. Steel Corp.	McKeesport, Pa.	1	325,000	Natural gas	Scrubber		
	S. Chicago, Ill.			Natural gas	ESP		
Bethlehem Steel Corp.	Lackawanna, N.Y.	2	1,100,000	Coke oven gas	ESP		Scrubber
	Sparrows Point, Md.	6	3,600,000	Coke oven gas	ESP	Baghouse	Scrubber
	E. Steubenville, W.Va.	1	4,250,000	Coke oven gas	Scrubber		Baghouse
W-P Steel Corp.		1	550,000	Coke oven gas	Scrubber		
Armco Steel Corp.	Middletown, Ohio	1	900,000		Scrubber	Recycle	Baghouse
National Steel Corp.	Ecourse, Mich.	1	2,000,000	Coke oven gas	Scrubber		
	Wiererton, W.Va.	1			Gravel bed		
Bethlehem Steel Corp.	Burns Harbor, Ind.	1	2,000,000		Scrubber	Baghouse	Baghouse
National Steel Corp.	Granite City, Ill.	1	1,000,000	Coke oven gas	Scrubber		

(continued)

APPENDIX A-1. (continued).

Company	Location	No. of strands	Estimated annual capacity, net tons	Ignition fuel	Machine windbox	Machine discharge	Crushing & screening
I-H, Wisconsin Steel	S. Chicago, Ill.	1	500,000	Coke oven gas	Scrubber		
Inland Steel	E. Chicago, Ill.	1	1,530,000		Cyclone, ESP-Baghouse		Baghouse
Lone Star Steel Co.	Lone Star, Tex.	1	300,000	Natural gas	Scrubber		
U.S. Steel Corp.	Geneva, Utah	2	900,000	Mixed gas	ESP	Scrubber	
	Gary, Ind.	3		Natural gas	ESP		Baghouse
Republic Steel	Gadsden, Ala.	1	400,000	Natural gas	Baghouse		Baghouse

Based on data from EPA 600/2-76-002, January 1976. "Control of Reclamation (Sinter) Plant Emissions using Electrostatic Precipitators", by John Varga, Jr., Battelle-Columbus Laboratories.

APPENDIX A-2. INVENTORY OF OPEN HEARTH FURNACES^a

Company	Location	No. of furnaces	Furnace capacity, net tons	Estimated annual capacity, net tons	Type of control equipment
Bethlehem Steel Corp.	Sparrows Point, Md.	7	420	3,500,000	ESP
Bethlehem Steel Corp.	Johnstown, Pa.	8	130	2,300,000	ESP
J & L Steel Corp.	Pittsburgh, Pa.	6	350	3,000,000	ESP
Lukens Steel Co.		6	145	300,000	
U.S. Steel Corp.	Fairless, Pa.	9	395	3,500,000	ESP
	Rankin, Pa.	10	320	3,250,000	ESP
Armco Steel Corp.	Middletown, Ohio	6	300	1,250,000	Scrubbers
Cyclops Corp.	Portsmouth, Ohio	3	300	750,000	
U.S. Steel Corp.	Youngstown, Ohio	15	160	1,500,000	ESP
YS & T Co.	Campbell, Ohio	7	200	1,100,000	ESP
	Youngstown, Ohio	11	185	1,500,000	
Inland Steel Co.	East Chicago, Ind.	7	335	2,000,000	ESP
Republic Steel Corp.	South Chicago, Ill.	4	250	800,000	ESP
U.S. Steel Corp.	Geneva, Utah	10	340	3,500,000	ESP
Kaiser Steel Corp.	Fontana, Cal.	8	225	1,500,000	ESP
U.S. Steel Corp.	Torrance, Cal.	4	60	125,000	ESP
Pacific States Steel Co.	Union City, Cal.	4	150	265,000	

^a "Cost of Clean Air," Battelle Memorial Institute, 1974.

APPENDIX A-3. SURVEY OF BOF PLANTS IN THE U.S.^a

Company	Plant Location	Date of Start-up	Furnaces No. & Size	Gas Cooling	Dust Removal Sys.	Blowing Rate		Gas Cleaning System	
						Design Max. SCFM	Present SCFM	Capacity-SCFM	Motor Power
Alan Wood Steel Co. Allegheny Lullum Steel Corp. Armco Steel Corp.	Conshohocken, Pa.	1968	2 x 150	Water sprays	Precipitator	15,000	13,000	600,000	1400 HP
	Natrons, Pa.	1966	2 x 80	Water	Scrubber	6,500	6,500	314,000 @ 550°F	3550 HP
	Ashland, Ky.	1963	2 x 180	Water sprays	Precipitator	15,000	15,000	700,000	
	Middletown, Ohio	1969	2 x 210	Water	Scrubber	22,500	19,000	55,000	2000 HP
Bethlehem Steel Corp.	Lackawanna, N.Y.	1964/66	3 x 300	Water sprays	Scrubber	25,000	26,000	1,000,500	900 HP
	Sparrows Point, Md.	1966	2 x 215	Water sprays	Venturi Scrubber	22,000	22,000	700,000	7500 HP
	Bethlehem, Pa.	1968	2 x 270	Water sprays	Precipitator	22,000	22,000	1,500,000	
	Burns Harbor, Ind.	1969	2 x 300	Water quench	Scrubber ^b	35,000	32,000	570,000 @ 180°F	4500 HP
C F & I Steel Corp. Crucible Inc. Ford Motor Co. Inland Steel Co.	Johstown, Pa.	1976	1 x 300						
	Pueblo, Colo.	1978	2 x 200						
	Midvale, Pa.	1961	2 x 120	Water sprays	Precipitator	6,500	11,000	300,000	700 HP
	Dearborn, Mich.	1968	2 x 105	Water quench	Scrubber	11,000	14,000	350,000	5000 HP
Interlake, Inc. Jones & Laughlin Steel Corp.	East Chicago, Ind.	1964	2 x 250	Water sprays	Precipitator	22,000	21,000	1,500,000	
		1966	2 x 255	Water quench	Venturi Scrubber	22,000	25,000		
	Chicago, Ill.	1974	2 x 210	Water quench	Scrubber	4,000	6,800	200,000 @ 200°F	500 HP
	Alaquippa, Pa.	1959	2 x 75	Water sprays	Precipitator	6,000		228,000 @ 560°F	
Kaiser McLouth National Steel, Great Lakes	Cleveland, Ohio	1957	2 x 80	Water sprays	Precipitator	13,000	17,000	1,300,000	5000 HP
		1968	3 x 190	Water sprays	Precipitator	20,000	18,000	550,000	
	Fontana, Calif.	1961	2 x 225	Water sprays	Precipitator	13,000	13,000		
	Trenton, Mich.	1958	3 x 120	Water sprays	Disintegrator	10,000	10,000		
Weirton Steel Div. Granite City Steel Co. Republic Steel Corp.	Boorae, Mich.	1962	2 x 300	Water sprays	Precipitators	26,000	26,000	1,260,000	3000 HP
	Weirton, W. Va.	1970	2 x 235	Water sprays	Precipitators	18,000	18,000	650,000	1600 HP
	Granite City, Ill.	1967	2 x 350	Water sprays	Scrubber	25,000	25,000	420,000 @ 140°F	
	Warren, Ohio	1965	2 x 235	Water sprays	Precipitator	22,000	22,000	1,000,000	
Sharon Steel Corp. United States Steel Corp.	Gadsden, Ala.	1965	2 x 190	Water sprays	Precipitator	15,000	14,000	720,000	1800 HP
	Cleveland, Ohio	1965	2 x 180	Water sprays	Precipitator	15,000	14,000	700,000 @ 550°F	
	Buffalo, N.Y.	1966	2 x 245	Water sprays	Scrubber ^b	15,000	20,000		
	South Chicago, Ill. (Q-BOP) ^d	1970	2 x 130		Scrubber ^c	9,000			
Wheeling-Pittsburgh Steel Corp. Wisconsin Steel Youngstown Sheet & Tube Co.	Farrell, Pa.	1974	2 x 200						
	Duquesne, Pa.	1963	1 x 150	Water quench	Venturi Scrubber	20,000	20,000	202,000 SCFM	2250 HP
	Gary, Ind. (I-D)	1965	2 x 215	Water quench	Venturi Scrubber	20,000	20,000	47,500	
	Gary, Ind. (Q-BOP) ^d	1973	3 x 200	Water sprays	Venturi Scrubber	20,000	19,000		
	South Chicago, Ill.	1969	3 x 200	Water quench	Venturi Scrubber	20,000	20,000		
	Lorain, Ohio	1971	2 x 225	Water	Venturi Scrubber	20,000	24,000	600,000 @ 550°F	
	Franklin, Pa.	1972	2 x 230	Water sprays	Venturi Scrubber	15,000	15,000	570,000	2250 HP
	Fairfield, Ala. (Q-BOP) ^d	1974	2 x 200	Water sprays	Precipitator	23,000	21,000	630,000	3750 HP
	Massena, Pa.	1964	2 x 285	Water	Venturi Scrubber	12,000	26,000		
	Steubenville, Ohio	1965	2 x 120	Water sprays	Precipitator				
	South Chicago, Ill.	1964	2 x 280	Water sprays	Precipitator				
	East Chicago, Ind.	1970	2 x 280	Water sprays	Precipitator				
	Campbell, Ohio	1976	2 x 200						

^a Based on data prepared by Process Development, Kaiser Engineers Inc., Chicago, Ill., revised July, 1975.

^b Suppressed combustion (recent retrofit).

^c Assumed to be scrubber - no other details available.

^d Q-BOP employs oxygen and natural gas blown through tuyeres in the bottom.

APPENDIX A-4. SURVEY OF ELECTRIC ARC FURNACES IN THE UNITED STATES^a

Company	Location	Number Furnaces	Year	Furnace Capacity net tons	Estimated Annual Capacity net tons ^b	Type of Control Equipment
A-L Industries Inc.	Brackenridge, Pa.	1	1925	25	400,000	Baghouse
		2	1928	10		
		2	1929	10		
		2	1941	35		
		1	1943	55		
		2	1949	70		
Armco Steel Corp.	Butler, Pa.	2	1949	80	1,000,000	Direct extraction and individual scrubbers
		1	1948	60		
		3	1969	165		
Babcock and Wilcox Co.	Beaver Falls, Pa.	2	1942	25	200,000	Building evacuation to baghouse
		1	1951	50		
		1	1952	75		
		1	1957	25		
		1	1967	50		
		1	1967	100		
B-L-H Corp.	Koppel, Pa.	1	1968	50	425,000	Building evacuation to baghouse
		1	1968	50		
		1	1968	75		
		1	1968	100		
		1	1958	18		
		1	1958	40		
Bethlehem Steel Corp.	Burnham, Pa.	1	1965	45	200,000	Furnace hoods and baghouse
		1	1971	70		
		1	1938	25		
		2	1940	50		
		2	1957	50		
		1	1977			
Bethlehem Steel Corp.	Bethlehem, Pa.	1	1969	150	1,000,000	Furnace hoods and baghouse
		2	1970	150		
		1				
	Steelton, Pa.	2	1969	150	800,000	Furnace hoods and baghouse
		1	1970	150		

APPENDIX A-4. (continued).

Company	Location	Number Furnaces	Year	Furnace Capacity net tons	Estimated Annual Capacity net tons	Type of Control Equipment
Judson Steel Corp.	Emeryville, Cal.	1	1969	30	100,000	Direct extraction to ESP canopy to baghouse
Pacific States Steel Corp.	Union City, Cal.	—	—	—	100,000	
Soule Steel Co.	Long Beach, Cal.	1	1959	15	105,000	
Southwest Steel Rolling Mills, Inc.	Los Angeles, Cal.	1	1969	15	108,000	Building evacuation, baghouse
		1	1948	15		
		1	1952	15		
Hawaiian Western Steel		1	—	35	100,000	
Keystone Steel & Wire Co.	Cortland, N.Y.	—	—	—	—	
Simonds Saw & Steel Co.	Lockport, N.Y.	3	—	15	—	Furnace hood, baghouse
Cabot, Corp.	Pampa, Texas	1	—	10	15,000	
Cameron Iron Works	Houston, Texas	1	—	60	75,000	
Firewater Corp.	Oakmont, Pa.	1	1964	45	65,000	Side hoods & furnace hood
Meca Machine Co.	West Haverstead, Pa.	1	1971	50	70,000	Baghouse
Midvale-Heppenstall Co.	Philadelphia, Pa.	1	—	30	270,000	Furnace hood & side hood
		1	—	50	—	
		1	—	100	—	
Baldwin-Lima-Hamilton Corp.	Burnham, Pa.	1	1958	18	200,000	Furnace hoods, baghouse
		1	1958	40	—	
		1	1965	45	—	
		1	1971	70	—	
Nasco	Latrobe, Pa.	1	1968	10	15,000	
Braeburn Alloy Steel	Braeburn, Pa.	2	—	6	10,000	
National Forge	Irvine, Pa.	1	—	1	240,000	
	Erie, Pa.	1	—	20	—	
		1	—	45	—	
		1	—	35	—	
		1	—	75	—	

^a "Cost of Clean Air" - Battelle Memorial Institute, 1974.

^b Where one figure is given for more than one furnace, the net tons refers to the total of all furnaces listed for that location.

(continued)

APPENDIX A-4. (continued).

Company	Location	Number Furnaces	Year	Capacity net tons	Estimated Annual Capacity net tons	Type of Control Equipment
Texas Steel Co.	Fort Worth, Texas	1	1923	3	200,000	Baghouse
		1	1942	7		
		1	1956	10		
		1	1958	20		
U.S. Steel Corp.	Cedar Pt., Texas	1	1968	30	550,000	Direct extraction quencher, venturi scrubber (individual)
		1	1967	200		
		1	1968	200		
		1	1975	120		
Chaparra Steel Co.	Midlothian, Texas	1	1962	70	400,000	
		1	1970	70		
Amco Steel Corp.	Sand Springs, Okla.	1	1957	20	50,000	
Rockwell Manufacturing Co.	Atchison, Kansas	1	1973	40	160,000	
Necor	Norfolk, Nebraska	2			500,000	
C F & I Corp.	Pueblo, Colorado	1	1959	15	180,000	Baghouse
Allison Steel Mfg. Co.	Tempe, Arizona	1	1960	15	500,000	Direct extraction, spray chamber, baghouse
		1	1968	25		
		2	1958	100		
Bethlehem Steel Corp.	Seattle, Wash.	1	1967	50	440,000	
Northwest Steel Rolling Mills, Inc.	Kent, Wash.	2	1969	25	100,000	Side hoods, baghouse
Cascade Steel Rolling Mills, Inc.	McMinnville, Oregon	1	1941	18	55,000	Side hoods, baghouse
		1	1942	18		
		1	1948	18		
		1	1968	75		
Jorgenson Co.	Seattle, Wash.	2	1957	40	160,000	
Aaron Steel	Etiwanda, Cal.	1	1961	10	80,000	
Amco Steel Corp.	Torrance, Cal.	1	1967	18	575,000	Building evacuation furnace hoods, baghouse
		1	1941	25		
		1	1948	75		
Bethlehem Steel Corp.	Los Angeles, Cal.	1	1950	100		
		1	1951	100		

APPENDIX A-4. (continued).

Company	Location	Number Furnaces	Year	Capacity net tons	Estimated Annual Capacity net tons	Type of Control Equipment
U.S. Steel Corp.	Chicago, Ill.	1	1941	50	750,000	Furnace hoods
		1	1941	85		
		1	1943	85		
		2	1970	200		
Republic-Finkl Columbia Tool Steel	Chicago, Ill.	2		60	350,000	Direct extraction, baghouse
	Chicago Heights, Ill.	1		5		
Harper Co.	Morton Grove, Ill.	1		8		
		1		4		
		1		10		
Ingersoll	New Castle, Ind.	2	1941	15	130,000	
Continental Steel	Kokomo, Ind.	2	1950	20		
		2	1968	150	425,000	Direct extraction, heat exchanger, baghouse
Inland Steel Corp.	Indiana Harbor, Ind.	2	1970	120	500,000	Direct extraction, roof truss hoods, baghouse
Joslyn Stainless Steel	Fort Wayne, Ind.	2		15	70,000	
		1	1963	25		
Iowa Steel Mill, Inc.	Cedar Rapids, Iowa	2	1975		150,000	Baghouse
Armco Steel Corp.	Kansas City, Mo.	1	1952	100	1,200,000	Direct extraction, spray chambers, baghouse
		1	1956	100		
		1	1962	150		
		1	1969	170		
Tennessee Forging Steel	Newport, Arkansas	1	1971	25	100,000	
Ross Steel Works	Amite, La.	1	1967	40	100,000	
Armco Steel Corp.	Houston, Texas	1	1951	100	400,000	Direct extraction
		1	1957	100		
		2	1966	175	1,200,000	Individual high-energy venturi, scrubbers
		1	1970	175		
		1	1971	175		
Border Steel Co.	Vinton, Texas	1	1960	25	140,000	Direct extraction, baghouse
		1	1967	25		
LaTourneau, Inc.	Longview, Texas	1	1951	25	100,000	
		3	1956	25		
Structural Metals,	Sequin, Texas	1	1962	25	90,000	Direct extraction, baghouse
		1	1964	25		

(continued)

APPENDIX A-4. (continued).

Company	Location	Number Furnaces	Year	Furnace Capacity net tons	Estimated Annual Capacity net tons	Type of Control Equipment
Urban Reclamation Technologies, Inc.	New Bedford, Mass.	1	1974-5	65	150,000	
Carpenter Technology Corp.	Bridgeport, Conn.	2	1955	35	110,000	Baghouse
Washburn Wire Co.	Phillipsdale, R.I.	2		45	120,000	
C F & I Steel Corp.	Trenton, N.J.	1	1964	45	220,000	Direct extraction, heat exchanger, baghouse
New Jersey Steel & Struct.	Sayreville, N.J.	2	1965	45	140,000	
		1	1971	50		
Intercoastal Steel Corp.	Chesapeake, Va.	1	1962	15	100,000	
Roanoke Electric Steel	Roanoke, Va.	1	1968	15	170,000	Direct extraction, baghouse
		1	1955	6		
		1	1960	15		
		1	1966	15		
Tunken Roller Bear- ing Co.	Canton, Ohio	2	1926	40	1,000,000	Side Hoods and baghouse
		1	1938	90		
		1	1952	100		
		2	1953	100		Furnace, roof hood and side extraction, and baghouse
		1	1964	140		
		1	1965	100		
		1	1970	60		Sidehoods, baghouse
		1	1971	150		
American Compressed Steel	Cincinnati, Ohio	1		6		
Calumet Steel Ceco Corp.	Chicago Heights, Ill. Lemont, Ill.	2	1959	30	180,000	
		2	1958	30	225,000	Individual baghouse
		1	1959	30		
Jones & McKnight Steel	Kankakee, Ill.	1	1961	20	155,000	Hood evacuation, baghouse
Keystone Steel & Wire Co.	Peoria, Ill.	1	1962	22	600,000	
		2	1970	150		
Laclede Steel Co.	Alton, Ill.	2	1965	200	700,000	Flooded disc scrubber
Northwestern Steel & Wire	Sterling, Ill.	1		150	1,000,000	
		1		250		
		1		400		
Republic Steel Corp.	S. Chicago, Ill.	2		100	700,000	Direct extraction, heat exchanger, baghouse
		1		140		
		2		150		

(continued)

APPENDIX A-4. (continued).

Company	Location	Number Furnaces	Year	Furnace Capacity net tons	Estimated Annual Capacity net tons	Type of Control Equipment
Amco Steel Corp. Copperweld Steel Corp.	Marion, Ohio Warren, Ohio	1 4	1968 1940	80 50	100,000 750,000	Baghouse
Cyclops Corp.	Manesfield, Ohio	1	1941	75	375,000	Direct extraction, side extraction, hoods, baghouse
J & L Steel Corp.	Cleveland, Ohio	1	1963	100	450,000	Direct extraction, ESP
Republic Steel Corp.	Canton, Ohio	2	1959	150	1,320,000	Direct extraction, baghouse
		5	1941	80		
		4	1967	200		
	Warren, Ohio	2	1957	185	450,000	
Cabot Corp.	Kokomo, Ind.	1		5		
General Motors Corp.		1		10	100,000	Baghouse
Jones & Laughlin Steel	Warren, Mich.	1	1933	65	350,000	Roof canopy hoods, building extraction, baghouse
		1	1938	65		
		1	1942	65		
		2	1949	65		
		1	1954	30	480,000	Scrubber
McLouth Steel Corp.	Trenton, Mich.	2	1954	200	400,000	Direct extraction, spray tower, baghouse
National Steel Corp.	Ecouse, Mich.	2	1968	150		
Ford Motor Co. Michigan Seamless Tube Co.	Dearborn, Mich. Jackson, Mich.	2 1	1975 1974	200	750,000 100,000	
Allegheny Ludlum Ind.	Watervliet, N.Y.	2 1 1		25 15 12.5	100,000	1972 building evacuation, baghouse
Crucible Steel Co. Roblin Industries, Inc.	Syracuse, N.Y. Dunkirk, N.Y.	1 1	1966 1963	35 25	60,000 150,000	(1970) Direct extraction, baghouse
Auburn Steel Co., Keystone Steel & Wire Co.	Auburn, N.Y. Cortland, N.Y.	1 1	1964 1974	25 55	165,000	
Sammonds Saw & Steel Co.						
Eastern Stainless Steel	Baltimore, Md.	1	1957	50	85,000	Baghouse
Amco Steel Corp.	Baltimore, Md.	2 1 3	1937 1941 1946	12 25 16	100,000	Baghouse

(continued)

APPENDIX A-4. (continued).

Company	Location	Number Furnaces	Year	Furnace Capacity net tons	Estimated Annual Capacity net tons	Type of Control Equipment
Interlake Steel Corp.	Newport, Ky.	2	1950	85	450,000	Baghouse
Jessop Steel Co.	Owensboro, Ky.	1	1965	85	120,000	
Kentucky Electric Steel	Coalten, Ky.	1	1950	60	120,000	Baghouse
		1	1956	60		
		1	1964	15		
		1	1968	15		
Connors Steel	Huntington, W. Va.	1	1950	50	150,000	Baghouse
		1	1959	50		
North Star Steel Co.	St. Paul, Minn.	1	1967	60	300,000	Direct extraction & furnace hoods, baghouse
		1	1970	60		
Jessop Steel Co.	Washington, Pa.	2		14	65,000	Canopy hoods and baghouse
		1		14		
		1	1962	20		
Latrobe Steel Co.	Latrobe, Pa.	1	1964	8	40,000	Direct extraction
		2	1964	30		
		1	1972	35		
Latrobe Forge and Spring Lukens Steel Co.	Latrobe, Pa.	1				
	Coatesville, Pa.	1	1958	100	850,000	Direct extraction, baghouse
		1	1962	100		
		1	1965	150		
		1	1973	150		
		1	1971	50	70,000	Baghouse
		1		30	270,000	Furnace hood and side hood
		1		50		
		1		100	100,000	
		1		20		
		1		45	140,000	
		1		35		
		1		75		
		1	1958	100	300,000	Furnace hood and baghouse
		1	1962	100		
		1		75		
		1	1942	75	350,000	Roof canopies, building evacuation and baghouse
		2	1942	100		
		1	1946	100		
		1	1953	30		
		2	1971	200	550,000	Building evacuation, baghouse
		1	1966	30	80,000	Furnace hood
		1	1966	40	80,000	
		1		10	15,000	Direct extraction and baghouse
		2	1968	35	45,000	
		1	1963			
Union Electric Steel Corp.	Fairless, Pa.	1				
Waco Inc.	Johnstown, Pa.	2				
Washington Steel Corp.	Pittsburgh, Pa.	1				
	Latrobe, Pa.	1				
	Washington, Pa.	2				

(continued)

APPENDIX A-4. (continued).

Company	Location	Number Furnaces	Year	Furnace Capacity net tons	Estimated Annual Capacity net tons	Type of Control Equipment
Phoenix Steel Corp.	Claymont, Del.	2	1968	150	525,000	Direct extraction, heat exchanger, baghouse
Florida Steel Corp.	Croft, N.C.	1	1961	15	100,000	Direct extraction, baghouse
		1	1965	80		
Georgetown Steel Corp.	Georgetown, S.C.	2	1968	70	300,000	Direct extraction, cooling tower, scrubbers (individual)
Nucor	Darlington, S.C.	1	1969	20	150,000	
		1	1970	20		
		1	1973	20		
		1	1973	20		
Owen Electric Steel Co.	Cayce, S.C.	2	1961	10	50,000	Baghouse
		1	1968	25		
Atlantic Steel Co.	Atlanta, Ga.	1	1952	85	450,000	Direct extraction, baghouse
		1	1956	85		
Florida Steel Corp.	Indiantown, Fla.	1	1970	30	90,000	Direct extraction, baghouse
		1	1974	35		
		1	1958	15		
		1	1961	20		
		1	1966	20		
		1	1966	20		
Ceco Corp.	Birmingham, Ala.	2	1955	6	90,000	Side hoods, baghouse
		1	1958	10		
		2	1972	30		
		2	1957	185		
Connors Steel Republic Steel Corp.	Birmingham, Ala. Gadsden, Ala.	1	1957	10	450,000	
		1	1963	10		
Mississippi Steel	Flowood, Miss.	1	1957	10	60,000	
Knoxville Iron	Knoxville, Tenn.	2	1964	10	100,000	
		1	1964	25		
Tennessee Forging Steel	Harriman, Tenn.	1	1966	20	150,000	
		1	1970	20		

(continued)

APPENDIX A-4. (continued).

Company	Location	Number Furnaces	Year	Furnace Capacity net tons	Estimated Annual Capacity net tons	Type of Control Equipment
Braeburn Alloy Steel Co.	Braeburn, Pa.	2 1		6 1	10,000	
Carpenter Tech. Corp.	Reading, Pa.	5		12	90,000	
Ceco Corp.	Milton, Pa.	2 1	1948 1958	22 22	170,000	Baghouse
Crucible Steel Corp.	Midland, Pa.	1 1 1 2	1939 1940 1941 1941	75 75 25 75	250,000	
Cyclops Corp.	Bridgeville, Pa.	4 1	1962	12 40	120,000	Direct extraction, side extraction, hoods, baghouse
Edgewater Corp.	Oakmont, Pa.	1	1964	45	65,000	Side hoods and furnace hood

APPENDIX A-5. SURFACE CONDITIONING AIR POLLUTION CONTROL SYSTEMS IN THE U.S. IRON

AND STEEL INDUSTRY^a

Company & location	Type of mill	Annual capacity		Type of control equipment	Gas flow	
		tonne	net tons		Nm ³ /min	ACFM ^b
Atlantic Steel Co. Atlanta, Ga.	Bloomng	435,456	480,000	Baghouse	c	
Armco Steel Corp. Houston, Tex.	Bloomng Slabbing	589,680 1,360,000	650,000 1,500,000	High-energy scrubber High-energy scrubber	3,996 2,834	141,000 100,000
Kansas City, Mo.	Bloomng	752,976	830,000	High-energy scrubber	1,304	46,000
Middletown, Ohio	Slabbing	2,358,720	2,600,000	High-energy scrubber	2,834	100,000
Babcock & Wilcox Co. Koppel, Pa.	Bloomng	453,600	500,000	High-energy scrubber	2,550	90,000
Bethlehem Steel Corp. Burns Harbor, Ind.	Slabbing	3,084,480	3,400,000	High-energy scrubber	3,117	110,000
Johnstown, Pa.	Bloomng Billet	2,195,424 884,520	2,420,000 975,000	High-energy scrubber Wet ESP	2,834 2,737	100,000 26,000
Los Angeles, Cal.	Bloomng	612,360	675,000	Baghouse	c	
Sparrows Point, Md.	Slabbing Bloomng	2,721,600 2,639,952	3,000,000 2,910,000	Wet ESP Wet ESP	4,251 708	150,000 25,000
Copperweld Corp. Warren, Ohio	Bloomng	480,816	530,000	Wet ESP ^d	1,417	50,000
Carpenter Technology Corp. Bridgeport, Conn.	Bloomng	181,440	200,000	Baghouse ^e		
CF & I Steel Corp. Pueblo, Colo.	Bloomng	563,371	621,000	d		
Crucible, Inc. Midland, Pa.	Bloomng	1,020,600	1,125,000	d		

(continued)

APPENDIX A-5. (continued).

Company & location	Type of mill	Annual capacity		Type of control equipment	Gas flow	
		tonne	net tons		Nm ³ /min	ACFM ^b
Ford Motor Co. Dearborn, Mich.	Slabbing	3,628,800	4,000,000	Water flume & sprays	2,692	95,000
Inland Steel Co. East Chicago, Ind.	Blooming Bloomi Slabbing	1,134,000 1,632,960 2,903,040	1,250,000 1,800,000 3,200,000	Water flume & sprays Water flume & sprays Water flume & sprays	2,550 2,267 2,834	90,000 80,000 100,000
J & L Steel Corp. Aliquippa, Pa.	Blooming	1,918,728	2,115,000	Wet ESP	3,542	125,000
Cleveland, Ohio	Slabbing	2,449,440	2,700,000	Wet ESP	2,834	100,000
Pittsburgh, Pa.	Blooming	1,647,475	1,816,000	Cyclones	2,834	100,000
Jessop Steel Co. Owensboro, Ky.	Blooming	145,152	160,000	Raghouse ^e		
Kaiser Steel Corp. Fontana, Cal.	Slabbing	2,830,464	3,120,000	Wet ESP	2,324	82,000
Lukens Steel Co. Coatesville, Pa.	plate	521,640	575,000			
Phoenix Steel Corp. Phoenixville, Pa.	f			Venturi scrubber		
Republic Steel Corp. Buffalo, N. Y.	Blooming	781,099	861,000	Wet ESP	1,700	60,000
Cleveland, Ohio	Blooming Slabbing Billet	925,344 2,574,634 635,040	1,020,000 2,838,000 700,000	Wet ESP Wet ESP Wet ESP	2,343 2,834 1,275	75,000 100,000 45,000
Youngstown, Ohio	Blooming	1,584,878	1,747,000	Raghouse ^e	1,417	50,000

(continued)

APPENDIX A-5. (continued).

Company & location	Type of mill	Annual capacity		Type of control equipment	Gas flow	
		tonne	net tons		Nm ³ /min	ACFM ^b
Roblin Steel Co. Dunkirk, N. Y.	g			Baghouse ^e		
Timken Co. Canton, Ohio	h	535,248	590,000	Baghouse	5,951	210,000
United States Steel Corp. Braddock, Pa.	Slabbing	2,268,000	2,500,000	Scrubber		
Duquesne, Pa.	Slabbing	1,496,880	1,650,000	Wet ESP	2,834	100,000
Fairless Hills Pa.	Blooming Slabbing	1,542,240 2,630,880	1,700,000 2,900,000	ESPI ESPI	2,343 3,259	75,000 115,000
Gary, Ind.	Slabbing Billet Rail Bar Bar	2,558,304 1,088,640 618,710 453,600 186,883	2,820,000 1,200,000 682,000 500,000 206,000	ESP ESP ESP ESP ESP	2,692 1,757 879 1,757 1,757	95,000 62,000 31,000 62,000 62,000
Homestead, Pa.	Slabbing	2,792,362	3,078,000	Multi-cyclones ^e	232	8,200
W-P Steel Corp. Steubenville, Ohio	Slabbing	1,385,294	1,527,000	Low-pressure scrubber		
Y.S. & T. Co. East Chicago, Ill.	Slabbing	2,363,348	2,604,000	High-energy scrubber	2,834	100,000
Campbell, Ohio	Blooming	1,545,869	1,704,000	High-energy scrubber	2,834	100,000

^a Battelle Memorial Institute; EPA Report No. 600/2-76-002.

^b ACFM - actual cubic feet per minute.

^c Scarfing emissions are exhausted to a common baghouse also controlling electric arc melting furnace emissions.

^d Under construction.

^e Conditioning of slabs, blooms, or billets is done by grinding.

^f Ingot scarfing.

^h Selective scarfing of cold billets at several scarfing stations.

ⁱ To be replaced by wet electrostatic precipitators.

APPENDIX A-6. SUBMERGED ELECTRIC ARC FERROALLOY FURNACES IN THE UNITED STATES^a

Company	Location	No. of furnaces	Year	Ferro- alloy produced	Furnace rating, kva	Estimated annual production, net tons	Equipment
Tenn. Metallurgy Co.		2		FeSi			
Tenn-Tex Alloy Corp.	Houston, Texas	1		FeMn			
Footo Mineral Co.	Wenatchee, Wash.	4	1942	FeSi	27,000	(45,000)	
Ohio Ferro-Alloys Corp.	Tacoma, Wash.	1	1941	FeCr	16,000	(31,000)	
Footo Mineral Co.	Graham, W. Va.	5	1952	FeMn			
		1	1953	FeSi			
		1	1965	FeCr			
		1	1967	FeCrS			
		1	1972	SiMn			
		1		50FeSi	54,700	(90,000)	
		1		75FeSi	54,700	(51,000)	
Diamond Shamrock	Kingwood, W. Va.	1		FeMn			
Union Carbide Corp.	Alloy, W. Va.	1	1932	FeSi+Si	12,000	(11,000)	Baghouse
		1		Lime-Mn	18,000		Baghouse
		1		Ore			
		1	1967	FeMn+Si	20,000	(65,000)	Baghouse
		1		FeCrSi	30,000	26,400	
		1		FeSi	30,000	(50,000)	
Ohio Ferro-Alloys Corp.	Powhatan, Ohio	1	1958	FeSi+Si			
		2	1959	FeSi+Si			
		1	1966	FeSi+Si	33,600		(1956)

(continued)

APPENDIX A-6. (continued).

Company	Location	No. of furnaces	Year	Ferro- alloy produced	Furnace rating, kva	Estimated annual production, net tons	Equipment
Union Carbide Corp.	Ashtabula, Ohio	1	1943				
		1	1951				
		1	1951				
		1	1967	FeSi	40,000	66,000	
		1	1975	FeSi	48,000	75,000	
	Marietta, Ohio	3	1951				
		1	1952	50FeCrSi	45,000	(75,000)	Scrubber
		1	1952	FeCrSi	25,000	(24,000)	Scrubber
		1	1953	75FeSi	20,000	(19,000)	
		2	1953				
New Jersey Zinc Co. Air Reduction Co., Inc. Chromium Mining & Smelting	Palmerton, Pa.	1	1968	SiMn	30,000	(29,000)	Scrubber
		1	1969				
		1	1969	FeCr	30,000	(60,000)	Scrubber
		2		FeMn	10,000	50,000	
		2	1971	HCFerCr	35,000	(130,000)	ESP
	Charleston, S. C. Woodstock, Tenn.	1		FeMn			
		1	1951	FeSi			
		1		FeCr			
		1		FeCrSi			
		1					
Air Reduction Co., Inc. Union Carbide Corp.	Niagara Falls, N. Y.	1	1960		25,000	47,000	Baghouse
	Niagara Falls, N. Y.	1					

(continued)

APPENDIX A-6. (continued).

Company	Location	No. of furnaces	Year	Ferro- alloy produced	Furnace rating, kva	Estimated annual production, net tons	Equipment
Hanna Nickel Smelting	Riddle, Oregon	4	1955	Ore Melt	14,000		
		2	1955	FeNi	2,500		
		1	1955	FeSi	13,500		
Union Carbide Corp.	Portland, Oregon	2	1941	FeSi	24,000	80,000	
		2	1956		12,600	37,000	
		2	1956		10,000		
Fonte Mineral Co.	Vancoram, Ohio (Steubenville)	1	1956	FeCr			
		3	1957	FeCr			
		1	1964	FeCrSi			
	Cambridge, Ohio	1	1965	FeCrSi			
		1	1953				
		1	1970				
Interlake Steel Corp.	Beverly, Ohio	1	1971				
		2	1953	HCFcCr	8,100	35,000	
		2	1954	HCFcCr	11,250		
		1	1963	FeSi+Si	29,000	(48,000)	
		1	1966	FeSi	26,500	(13,000)	
		1	1967	FeSi	36,000	(60,000)	
Ohio Ferro-Alloys Corp.	Brilliant, Ohio	3	1951				
		1	1965				
		2	1958				
	Philo, Ohio	2					
		2					
		2					
NI Industries	Niagara Falls, N. Y.	1	1966	50FeSi	60,000	(100,000)	
		1	1971	75FeSi	60,000	(57,000)	
		1		FeTi FeTi			(1965)

(continued)

APPENDIX A-6. (continued).

Company	Location	No. of furnaces	Year	Ferro- alloy produced	Furnace rating, kva	Estimated annual production, net tons	Equipment
Agrico Chemical Co.	Pierce, Fla.			FeP			
FMC Corp.	Pocatello, Idaho			FeP			
Hooker Chemical Co.	Columbia, Tenn.			FeP			
Mobil Chemical Co.	Nichols, Fla.			FeP			
Monsanto Co.	Soda Springs, Idaho			FeP			
Stauffer Chemical Co.	Mt. Pleasant, Tenn.			FeP			
	Silver Bow, Montana			FeP			
Tenn. Valley Authority	Musele Shoals, Ala.			FeP			
<u>Metalothermic Furnaces</u>							
Shieldalloy Corp.	Newfield, N. J.			FeV, FeTi, FeB, FeCb, etc.			
Climax Molybdenum Co.	Longeloth, Pa.			FeMo			
Kuwecki Chemical Co.	Easton, Pa.			FeCb			
Reading Alloys	Robesohia, Pa.			FeCb, FeV			
Molybdenum Corp. of America	Washington, Pa.			FeMo, FeW, FeCb			
Air Reduction Co., Inc.	Mobile, Ala.	1	1972	50FeSi	40,000	(65,000)	Net scrubber
Interlake, Inc.	Selma, Ala.	1	1966	FeSi	18,000	30,000	

(continued)

APPENDIX A-6. (continued).

Company	Location	No. of furnaces	Year	Pero- alloy produced	Furnace rating, kva	Estimated annual production, net tons	Equipment
Tenn. Alloys Corp.	Bridgeport, Ala.	2		FeSi			
Union Carbide Corp.	Theodore, Ala.	1	1940				
Woodward Iron Co.	Woodward, Ala.	1		FeSi			
Foot Mineral Co.	Keokuk, Iowa (8 furnaces)	1	1964	FeSi	9,000	(9,000)	
		1	1967	FeSi	54,700	90,000	
		1	1949		8,500		
		1	1949		11,000		
		1	1949		15,000		
		1			17,000		
		4			3,500		
		1			21,300		
		2	1965		48,000	180,000	Baghouse

a "Cost of Clean Air," Battelle Memorial Institute, 1974.

APPENDIX A-7. RESEARCH-COTTRELL PRECIPITATORS ON SINTER MACHINE GAS

Customer	No. of machines	Gas Vol/ machine	Temp.	Efficiency, %	Dust inlet
Tennessee Coal & Iron - U.S.	3	150,000 ft ³ /min	250°F	Guar. 90% Act. 95 - 98%	1.0 - 2.0 grains/SCF
U.S. Steel Corp. Geneva, Utah	2	140,000 ft ³ /min	450°F		
U.S. Steel Corp. Fairless Works	1	440,000 ft ³ /min	300°F	Guar. 95% Act. 95.5 - 97.4%	0.576 - .830 grains/SCF
Youngstown Sheet & Tube Indiana Harbor, Ind.	1	375,000 ft ³ /min	180 - 350°F	Guar. 93.75 Act. 98.7%	1.22 grains/SCF
U.S. Steel Corp. Edgar Thomas Works	1	193,500 ft ³ /min	250°F	Guar. 96.5%	1.4 grains/SCF
Bethlehem Steel Corp. Johnstown, Pa.	2	213,000 ft ³ /min	240°F	Guar. 98%	2 - 4 grains/ SCF
Bethlehem Steel Corp. Bethlehem, Pa.	4	385,000/ Pprt.	240°F	98	.02 grains/SCF

APPENDIX A-8

LIST OF RESEARCH-COTTRELL DESIGNED OXYGEN STEEL MAKING COTTRELL PRECIPITATORS

Customer & Location (Licensee)	No., Type & Size Furnaces	No. of Pptrs.	Total ft ³ /min Temp.	Eff. % Grs./SCF Outlet
U. S. Steel Corporation Torrance, California	4 Open Hearth 35 Ton	4	134,400 450°F	95.50 .03
U. S. Steel Corporation Provo, Utah	10 Open Hearth 250 Ton	8	440,000 500°F	96.00 .03
Jones & Laughlin Steel Corporation Aliquippa, Pa.	2 LD Converter 60 Ton	1	238,000 700°F	99.50 .05
Kaiser Steel Corporation Fontana, California	2 LD Converter 75 Ton	2	403,000 560°F	99.80 .0045
Jones & Laughlin Steel Corporation Pittsburgh, Pa.	1 Open Hearth 250 Ton	1	101,500 500°F	97.50 .025
Kaiser Steel Corporation Fontana, California	1 LD Converter 75 Ton	1	202,500 560°F	99.80 .0045
Bethlehem Steel Company Lackawanna, New York	3 Open Hearth 380 Ton	2	700,000 550°F	98.75 .03
Bethlehem Steel Company Lackawanna, New York	6 Open Hearth 275 Ton	2	700,000 550°F	98.75 .02
Republic Steel Corp. Chicago, Illinois	2 Open Hearth 265 Ton	2	300,000	99.00 .05
Bethlehem Steel Co. Johnstown, Pa.	8 Open Hearth 185 Ton	2	396,000 450°F	98.00 .05

(continued)

APPENDIX A-8. (continued)

LIST OF
RESEARCH-COTTRELL DESIGNED
OXYGEN STEEL MAKING
COTTRELL PRECIPITATORS

Customer & Location ---(Licensee)-----	No., Type & Size Furnaces	No. of Pptrs.	Total ft ³ /min Temp.	Eff. % Grs./SCF Outlet
Weirton Steel Company Weirton, West Virginia	2 Open Hearth 325 Ton	1	260,000 500°F	99.20 .02
Bethlehem Steel Bethlehem, Pennsylvania	2 Basic Oxygen 250 Ton	3	960,000 500°F	99.7 .05
Bethlehem Steel Franklin Works Johnstown, Pa.	8 existing 1 future O ₂ lanced O.H.	1	624,000	99.0 (0.5)
U. S. Steel Corp. Fairless Works Fairless Hills, Pa.	9 O.H.	2	1391,000	97 (.03)
U. S. Steel Corp. Ohio Works Youngstown, Ohio	10 of 12 O.H. fces.	2	556,000 (total)	98 (.05 wet)

APPENDIX A-9.

RESEARCH-COTTRELL, INC.
HIGH EFFICIENCY SCRUBBER INSTALLATIONS

Customer & Location	Application	# of Units	Gas Vol ft ³ /min Scrubber	PD in. H ₂ O	Outlet Conc. Gr/SCF
McLouth Steel Corporation Trenton, Michigan	Sinter Dedusting Systems	2	100,000	8	.03
Allison Steel Company Phoenix, Arizona	Elec. Furnace	2	9,000	40	.05
Allegheny Ludlum Steel Corp. Brakenridge, Pa.	B.O.F.	1	314,000	42	.05
Armco Steel Co. Sheffield Division Houston, Texas	Elec. Furnace	2	204,000	46	.05
Union Carbide Corporation Alloy, W.Va.	Elec. Furnace	2	115,000	55	.02
Union Carbide Corporation Marietta, Ohio	Silicon - Manganese Elec. Furnace	2	127,000	57	.035
Northwestern Steel & Wire Sterling, Illinois	Elec. Furnace	1	245,000	40	.05
Armco Steel Corp. Butler, Pa.	Elec Furnace	3	194,000	45	.035

APPENDIX A-9. (continued)

<u>Customer & Location</u>	<u>Application</u>	<u># of Units</u>	<u>Gas Vol ft³/min Scrubber</u>	<u>PD in. H₂O</u>	<u>Outlet Conc. Gr/SCF</u>
Armco Steel Corp. Houston, Texas	Elec. Furnace	1	204,000	46	.04
Kaiser Engineers for Armco Steel Corp. Middletown, Ohio	6 Open Hearth Furnaces	6	218,000	47	.03
S&B Engineers for Tenn-Tex Alloy Corp.	Ferrosilicon Electric Furnace	1	32,600	39	-
Armco Steel Corp. Houston, Texas	Electric Arc Furnace	1	204,000	46	.04
Union Carbide Corporation Marietta, Ohio	Ferrochromium Elec. Furnace	2	127,000	57	.035
S&B Engineers for Tenn-Tex Alloy Corp. Houston, Texas	Elec. Furnace	1	200,000	45	.05
Northwestern Steel & Wire Sterling, Illinois	Elec. Furnace	1	42,000	50	.02
U. S. Steel Corp. Fairless Works Fairless, Pa.	Elec. Furnace	2	42,000	50	.02

APPENDIX B-1

CAPITAL AND ANNUAL COSTS OF PRECIPITATORS ON SELECTED
IRON AND STEEL AND FERROALLOY PROCESSES

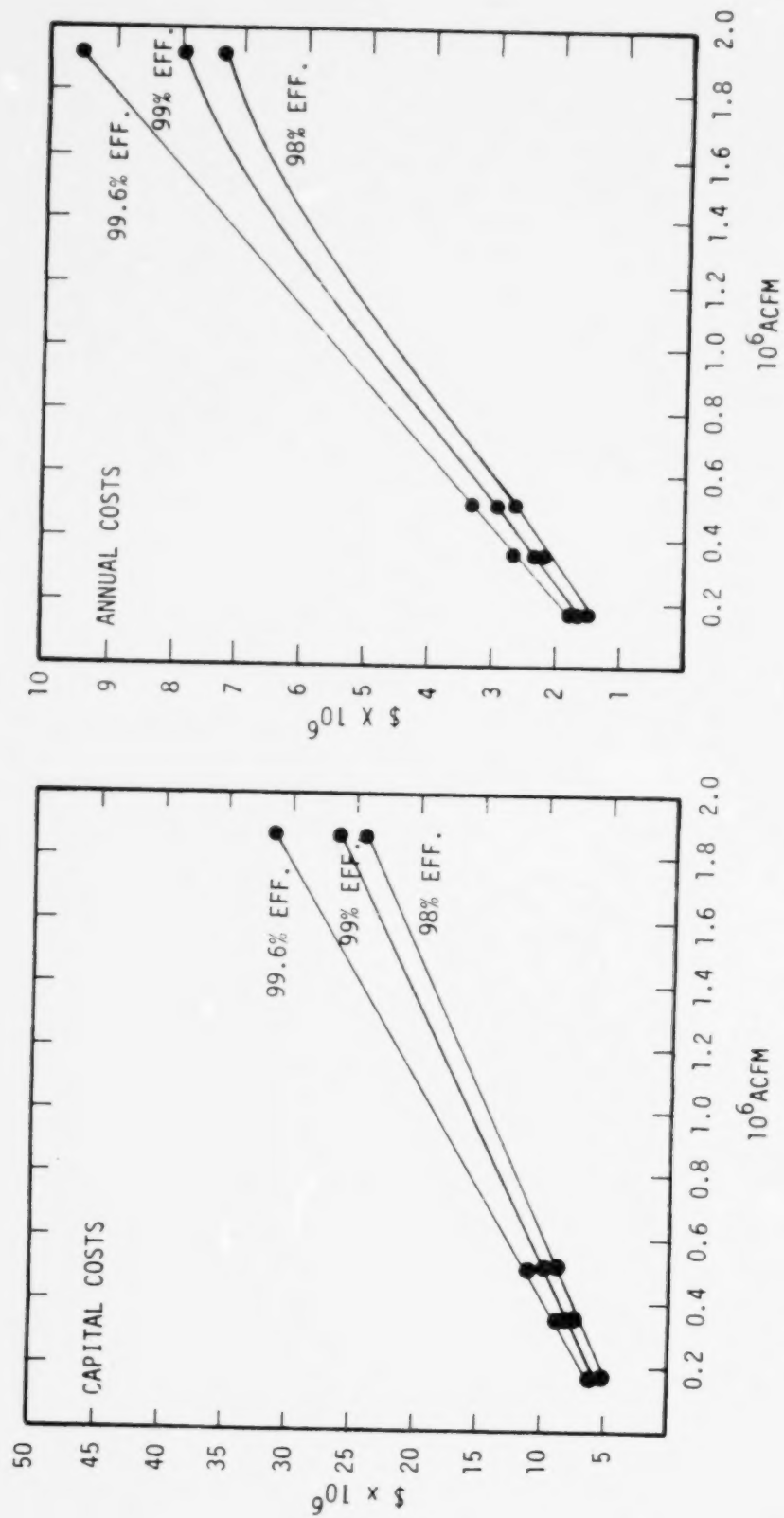


Figure B-1-1. Capital and annual costs of cold side ESP's on sintering windbox.

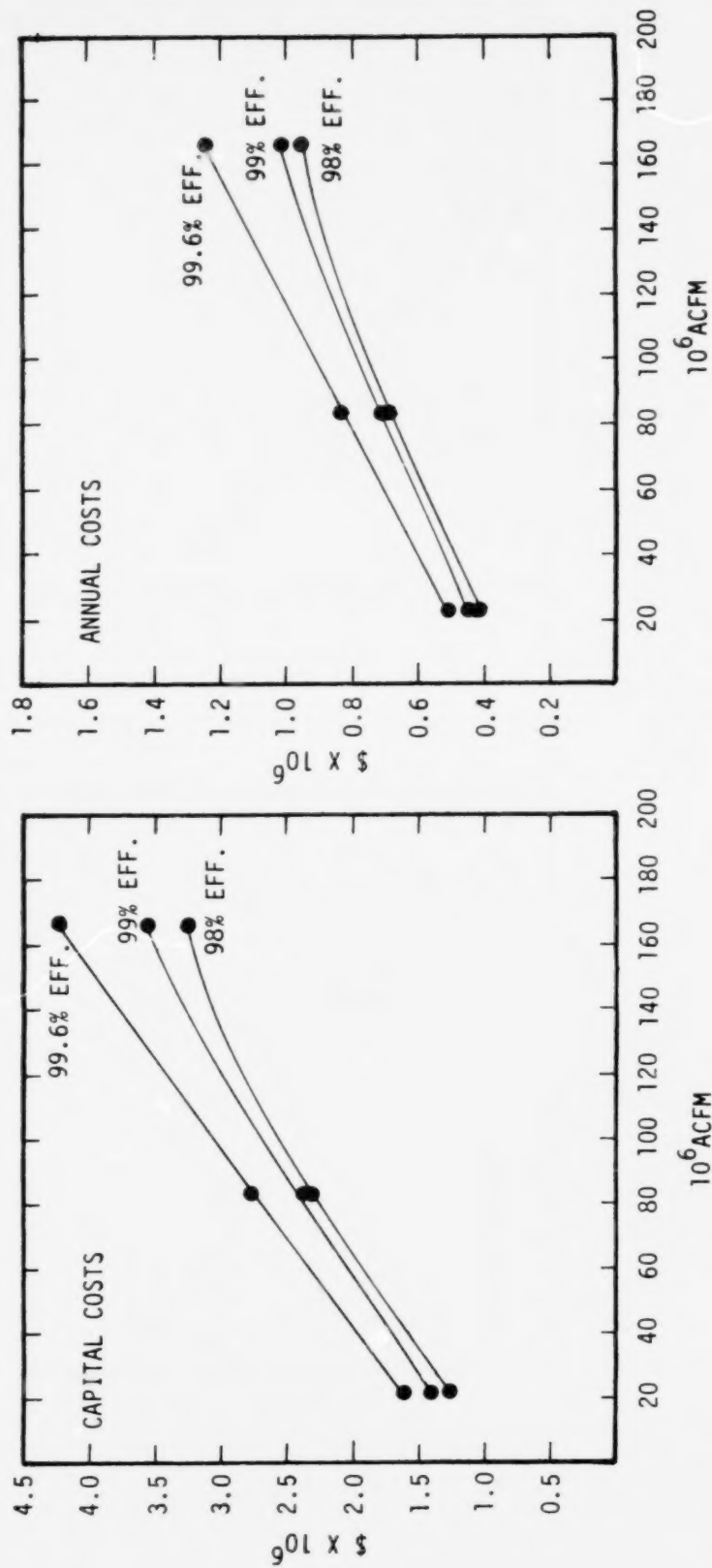


Figure B-1-2. Capital and annual costs of cold side ESP's on scarfing process.

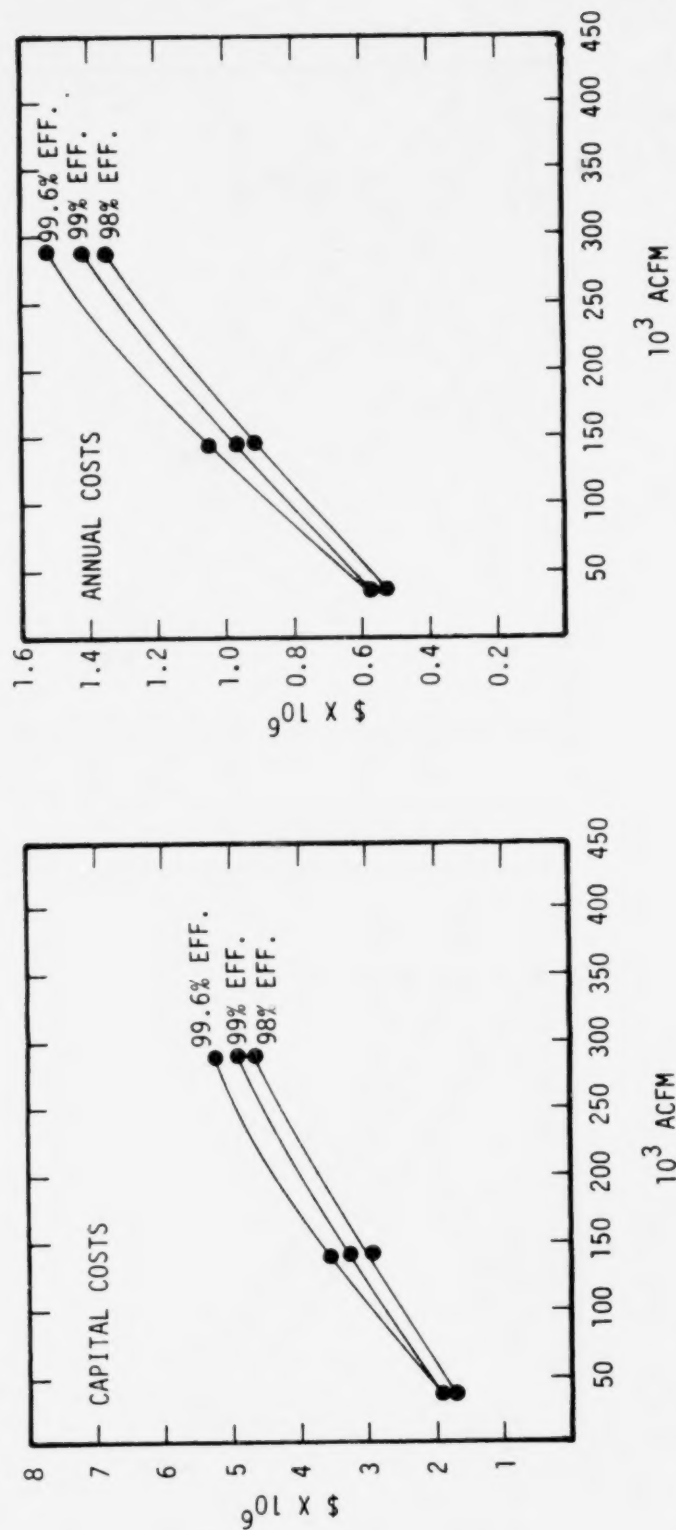


Figure B-1-3. Capital and annual costs of cold side ESP on open hearth furnace.

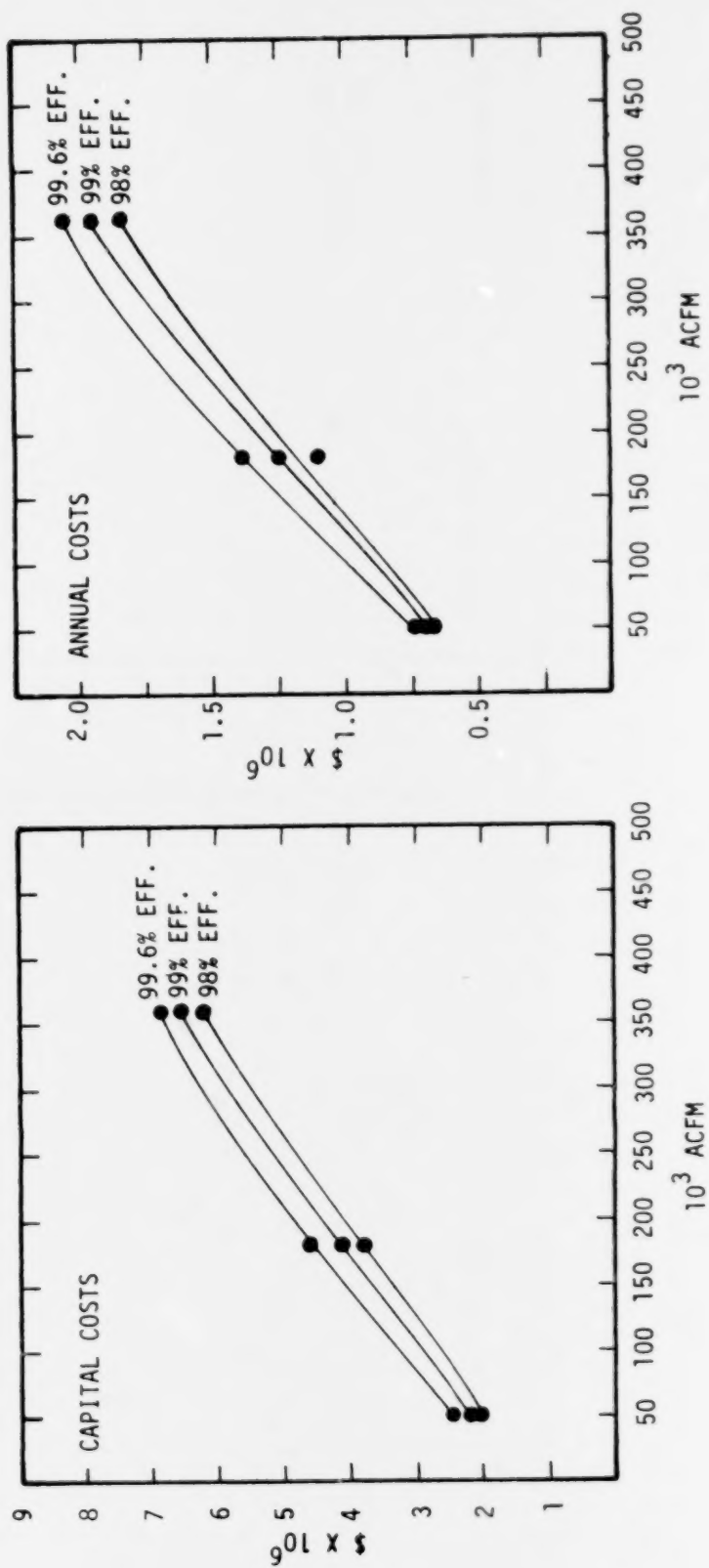


Figure B-1-4. Capital and annual costs of cold side ESP's on basic oxygen furnace.

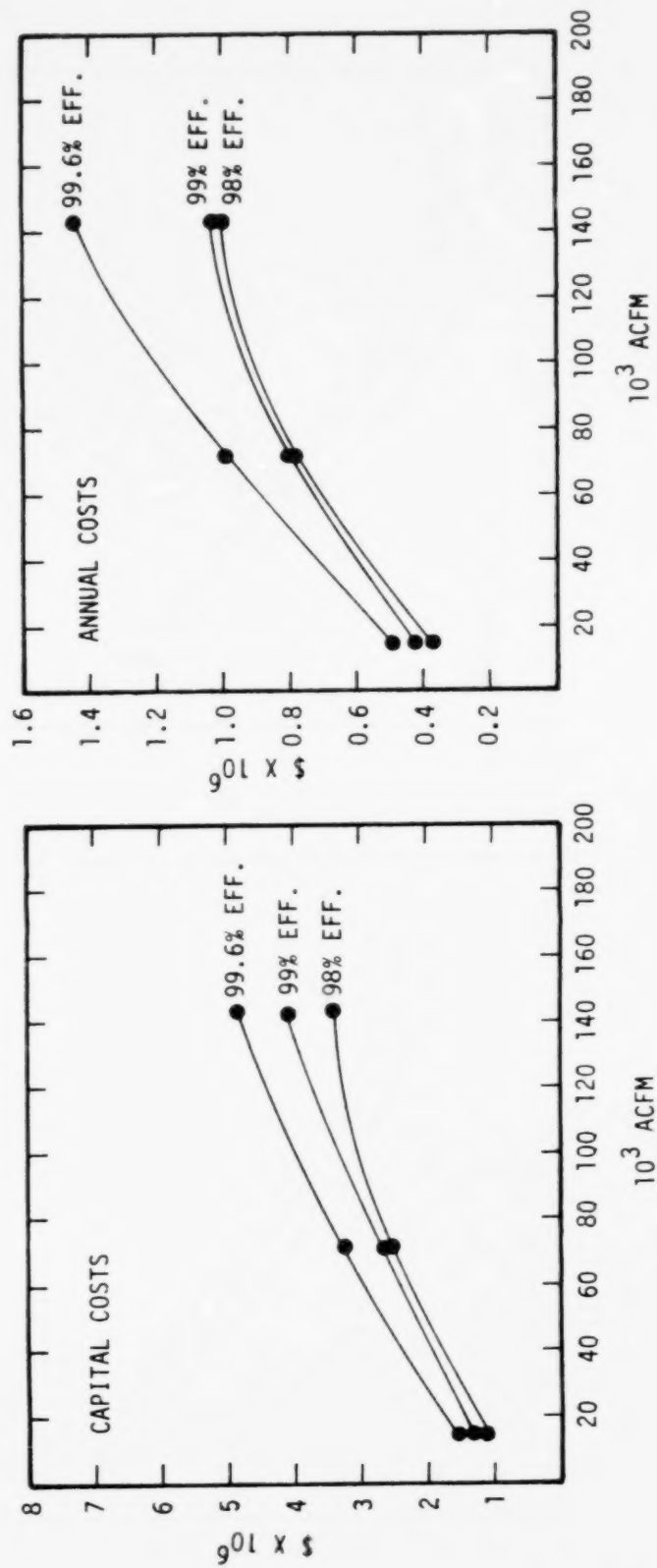


Figure B-1-5. Capital and annual costs of cold side ESP's on electric arc furnace.

APPENDIX B-2

CHECKLIST FOR OBTAINING DESIGN AND OPERATING DATA ON
PARTICULATE SCRUBBERS (Design and Operating Parameters)

Application _____
Vendor _____
Design type _____
No. of scrubber modules _____
Installed scrubber capacity, acfm _____
Reheat? _____
Capital cost, \$/kw _____
Dust composition _____
Gas composition _____
Actual gas flow, acfm _____
Gas flow/module _____
Temperature, °F _____
Diameter of scrubber, ft _____
Length of scrubber, ft _____
Gas velocity, fpm _____
Gas retention time, s _____
Particle size distribution _____
Inlet dust loading, gr/scfd _____
L/C, gal/1000 acf _____
Method of water injection type _____
Average droplet size, micron _____
Average droplet speed, ft/s _____
Open or closed loop system? _____
Total pressure drop, in. wg _____

APPENDIX B-2. (continued)

Overall collection efficiency, % _____

Fractional collection efficiency, % _____

Water requirement, acre-ft/yr _____

Electric power requirement, kW _____

Electric power, % of generating capacity _____

Manpower, total operators _____

Availability, % _____

APPENDIX B-3

VENTURI SCRUBBER CORRELATIONS BASED ON
RESEARCH COTTRELL COMPUTER PERFORMANCE MODEL

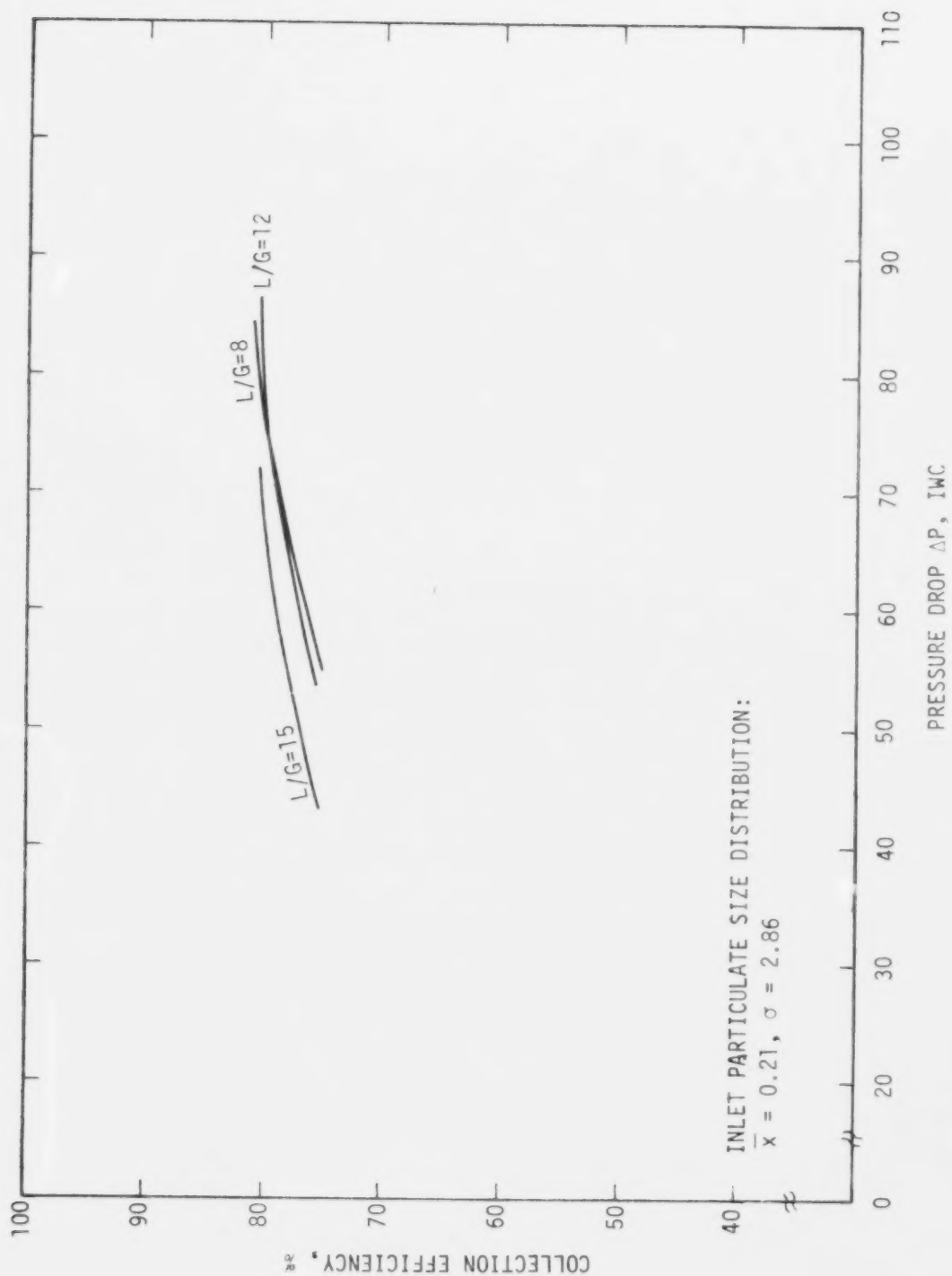


Figure B-3-1. Effects of pressure drop and L/G ratio on the particulate collection efficiency of venturi scrubbers for open

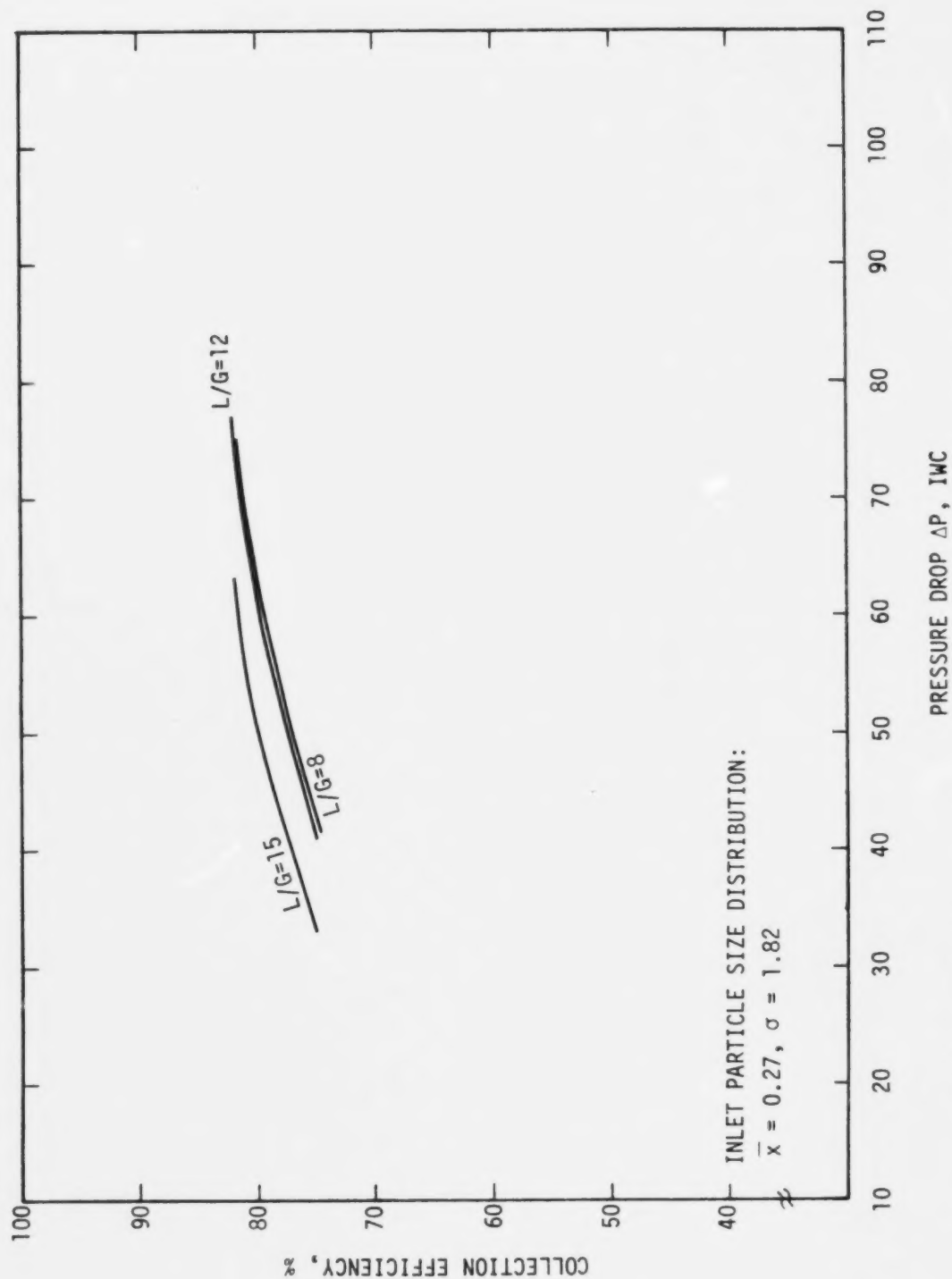


Figure B-3-2. Effects of pressure drop and L/G ratio on the particulate collection efficiency of venturi scrubbers for basic oxygen furnace gas ($T = 300^\circ\text{F}$).

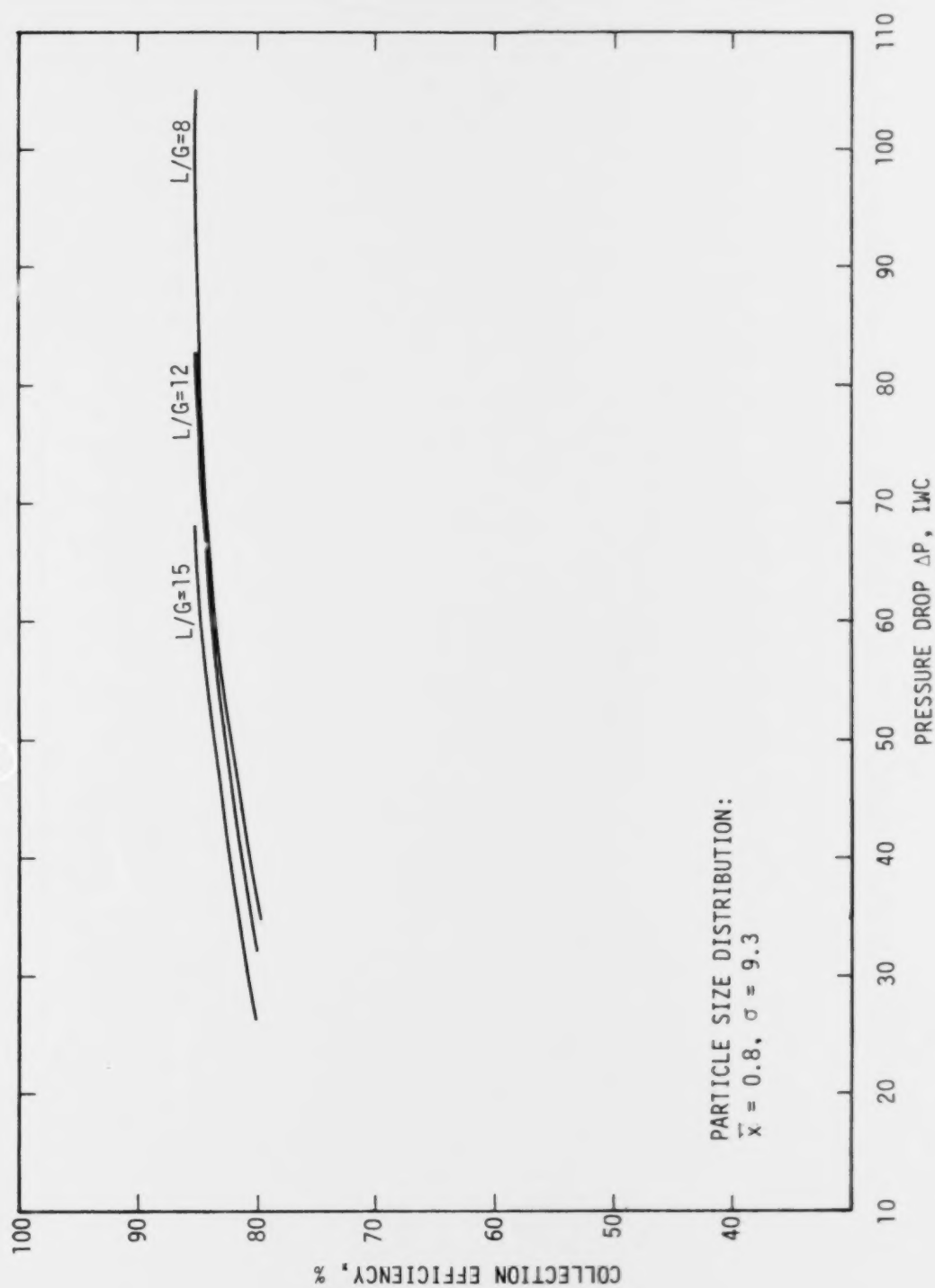


Figure B-3-3. Effects of pressure drop and L/G ratio on the particulate collection efficiency of venturi scrubbers for electric arc furnace gas

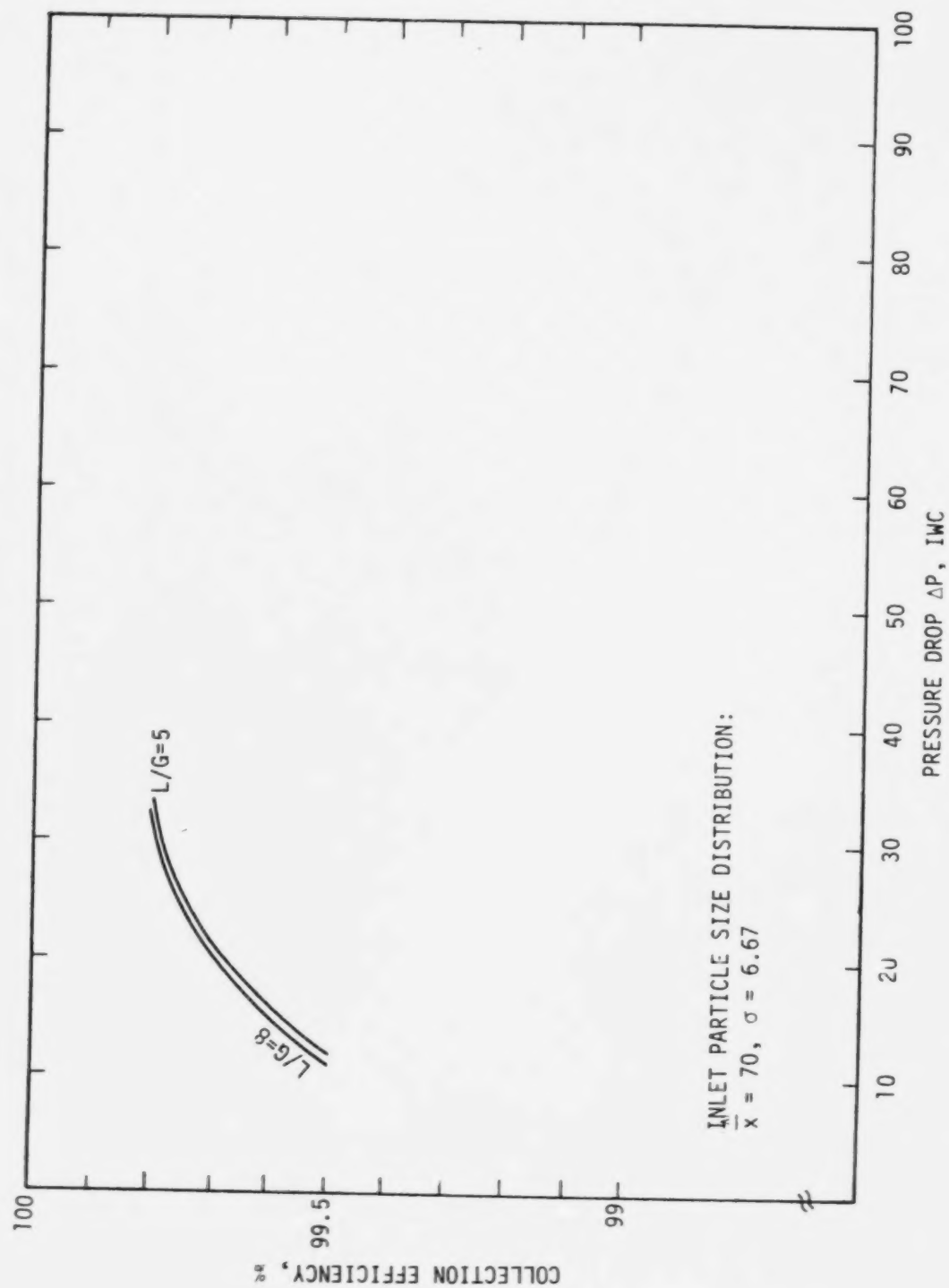


Figure B-3-4. Effects of pressure drop and L/G ratio on the particulate collection efficiency of venturi scrubbers for sintering machine gas ($T = 300^{\circ}\text{F}$).

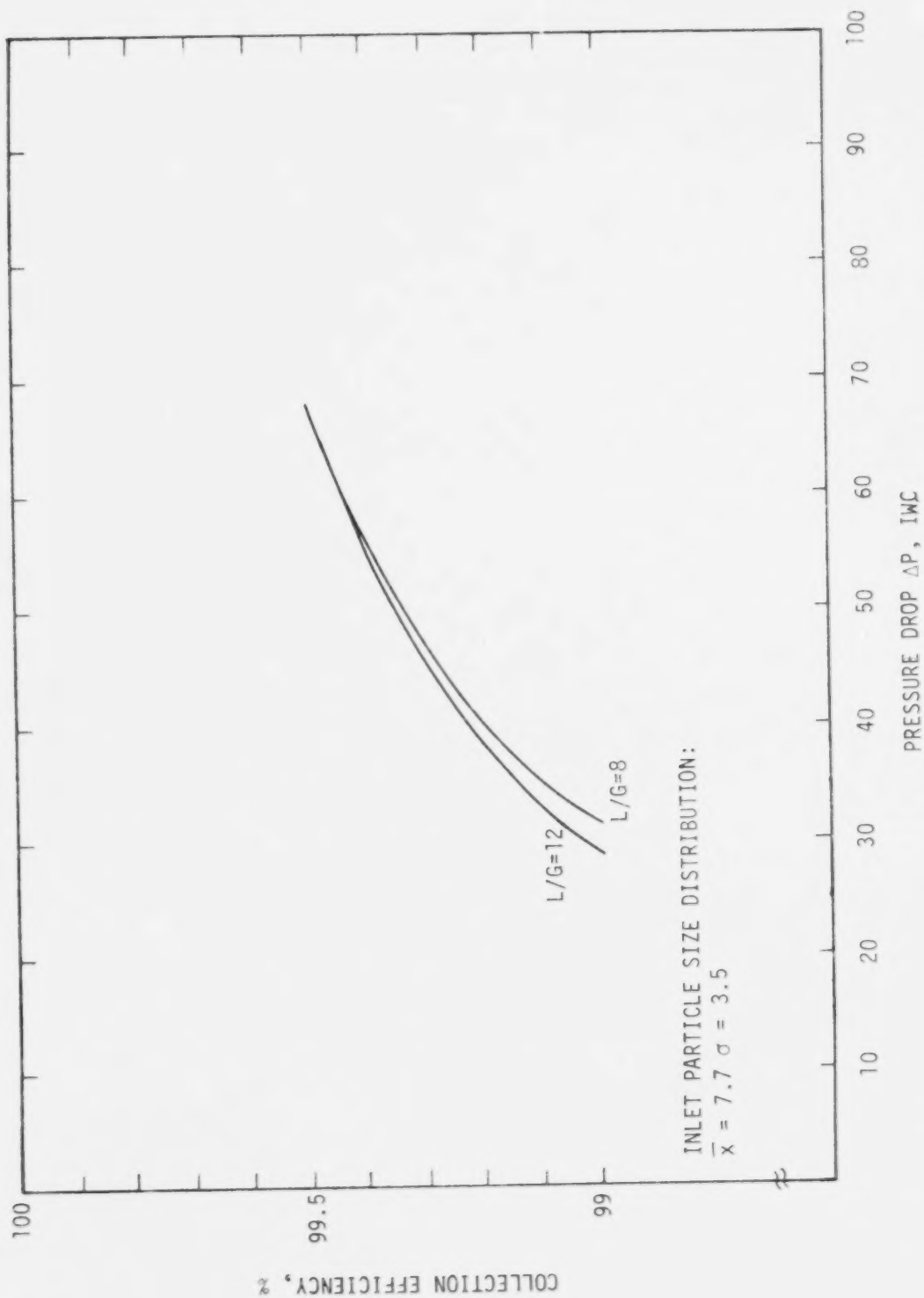


Figure B-3-5. Effects of pressure drop and L/G ratio on the particulate collection efficiency of venturi scrubbers for sintering machine gas pretreated with water-based collectors ($\bar{x} = 7.7$, $\sigma = 3.5$)

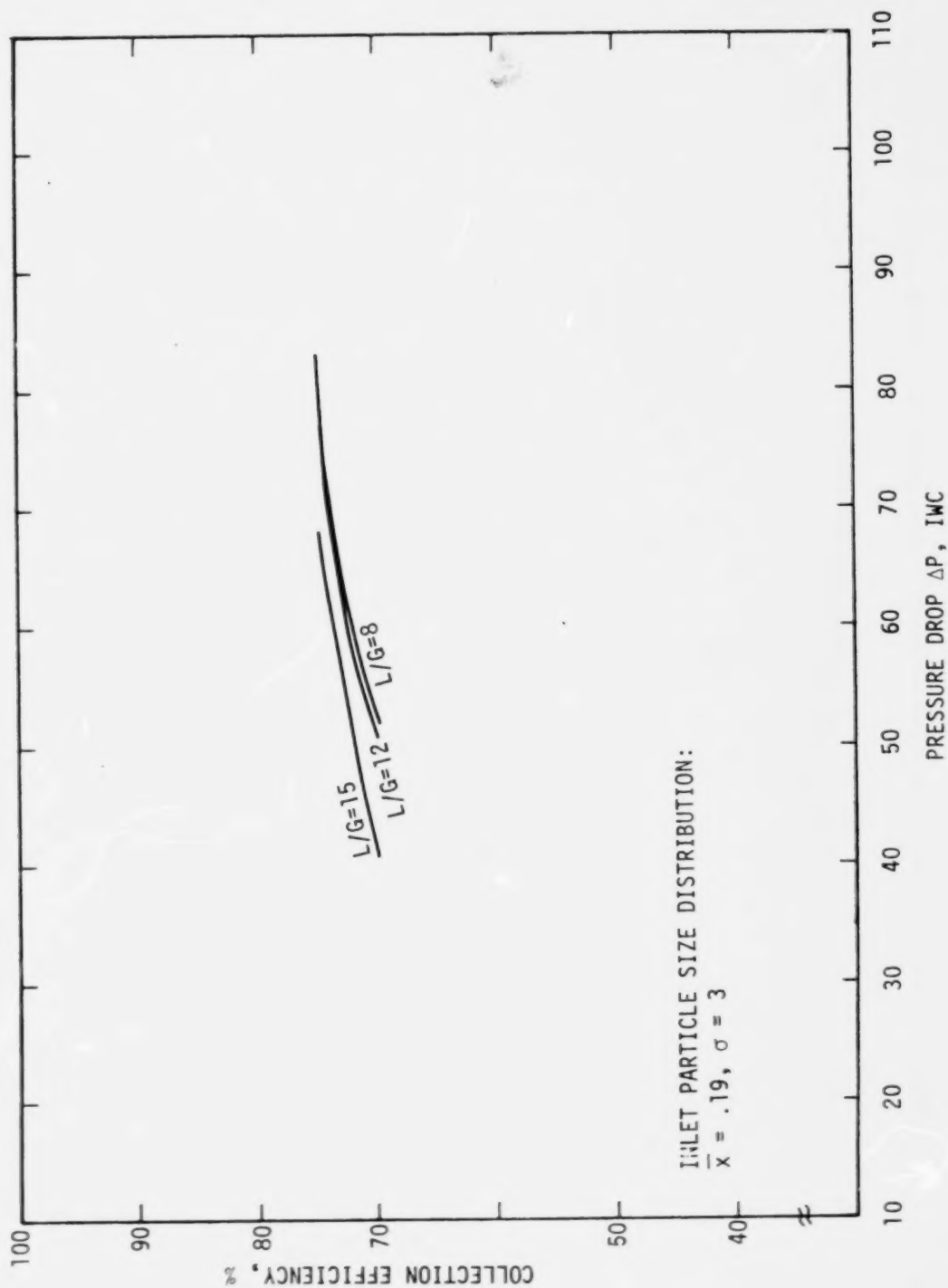


Figure B-3-6. Effects of pressure drop and L/G ratio on the particulate collection efficiency of venturi scrubbers for ferrosilicon arc furnace gas ($T = 300^{\circ}\text{F}$).

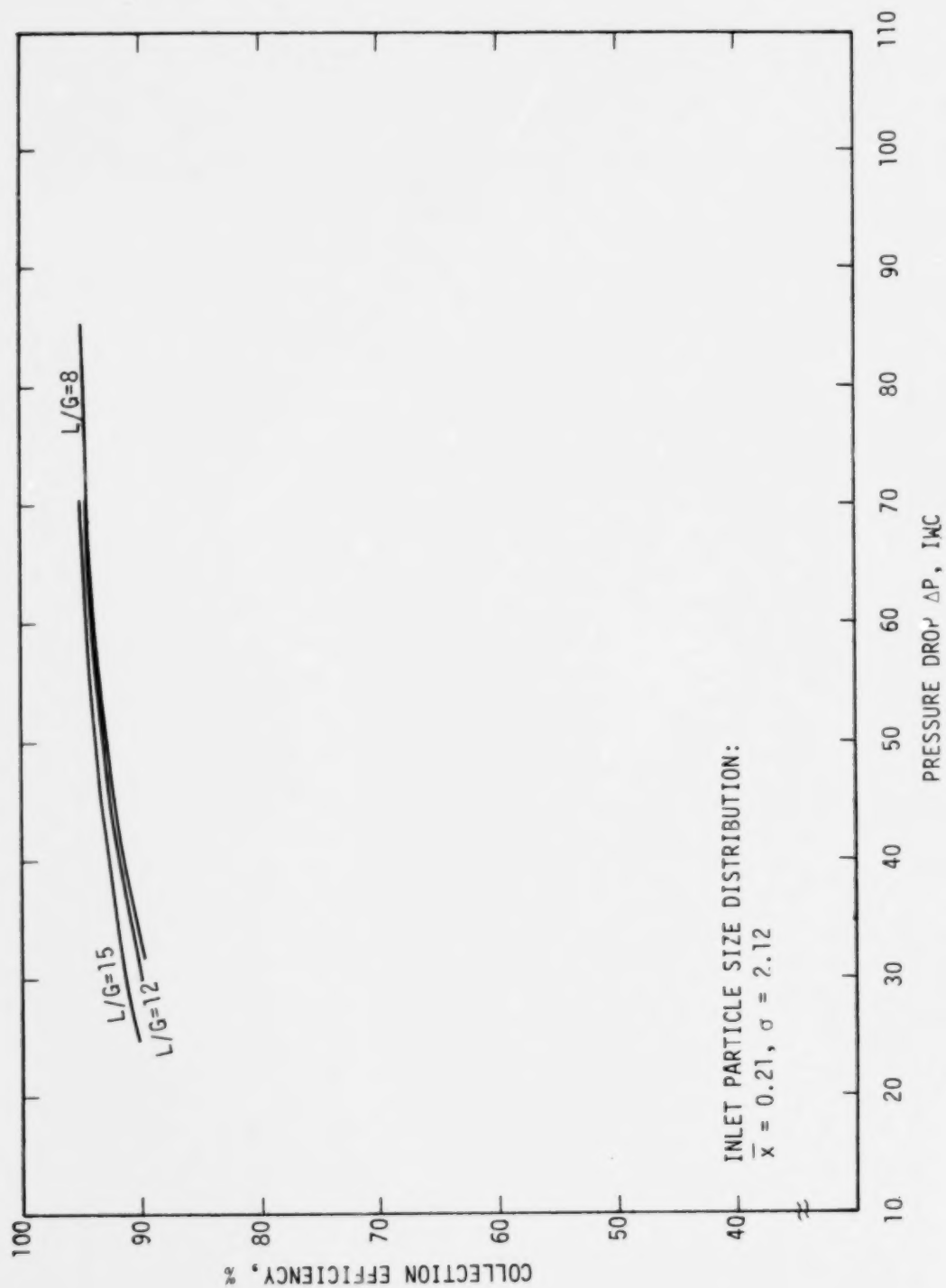


Figure B-3-7. Effects of pressure drop and L/G ratio on the particle collection efficiency of venturi scrubbers for ferromanganese arc furnace gas

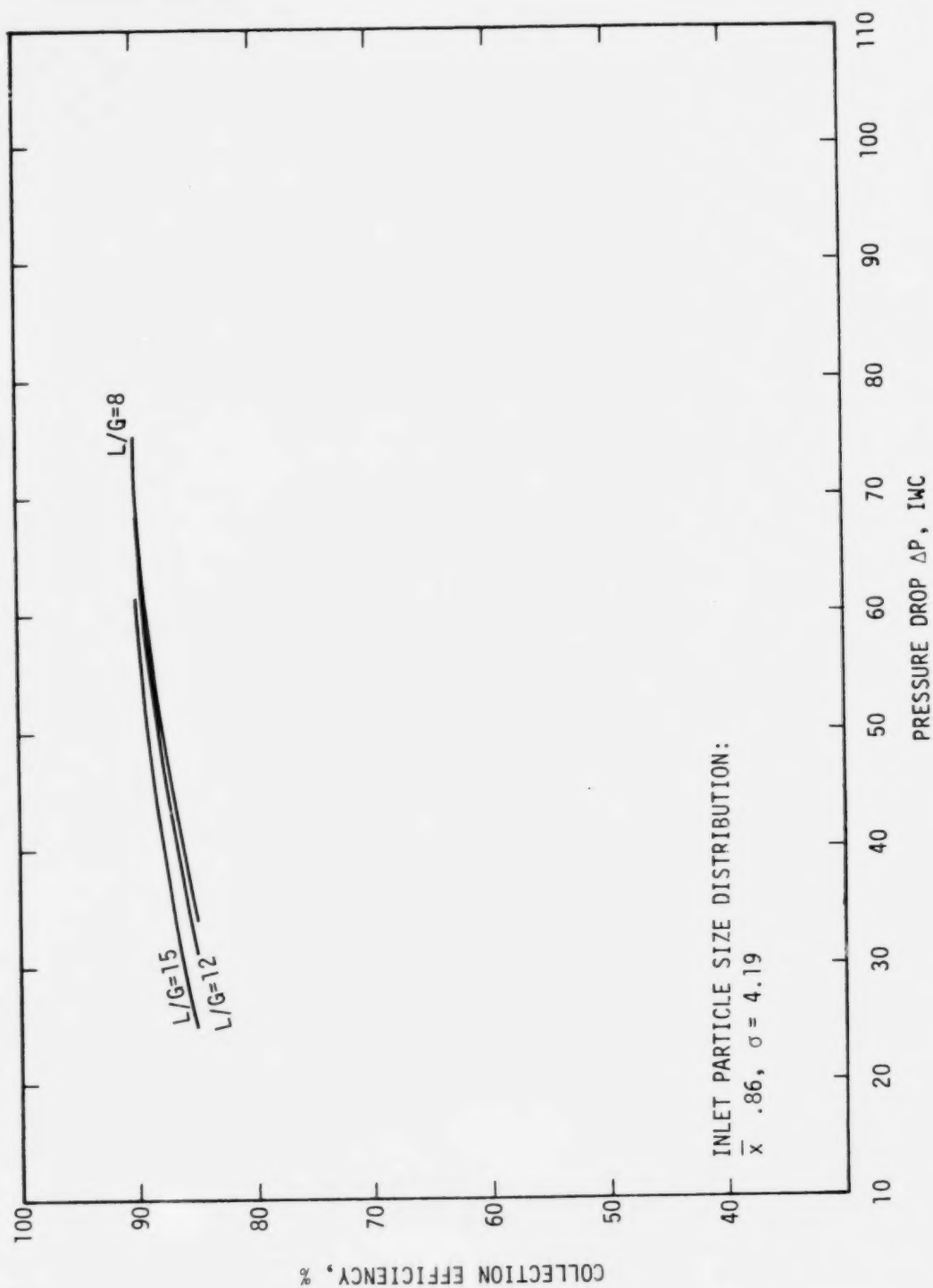


Figure B-3-8. Effects of pressure drop and L/G ratio on the particulate collection efficiency of venturi scrubbers for ferrochromium arc furnace ($T = 300^{\circ}\text{F}$).

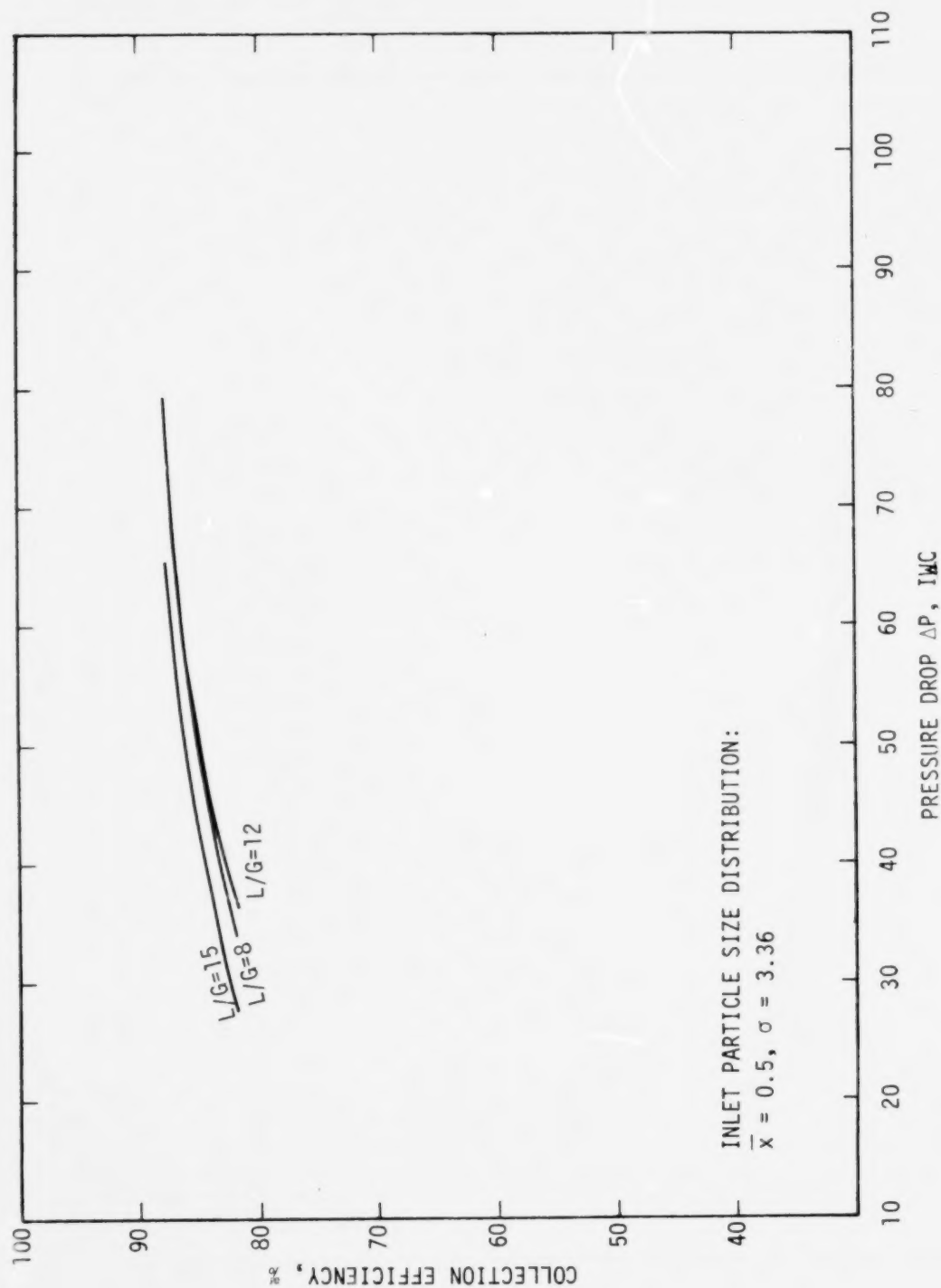


Figure B-3-9. Effects of pressure drop and L/G ratio on the particulate collection efficiency of venturi scrubbers for miscellaneous ferroalloy

APPENDIX B-4

CAPITAL AND ANNUAL COSTS OF VENTURI SCRUBBERS
ON SELECTED IRON AND STEEL AND FERROALLOY PROCESSES

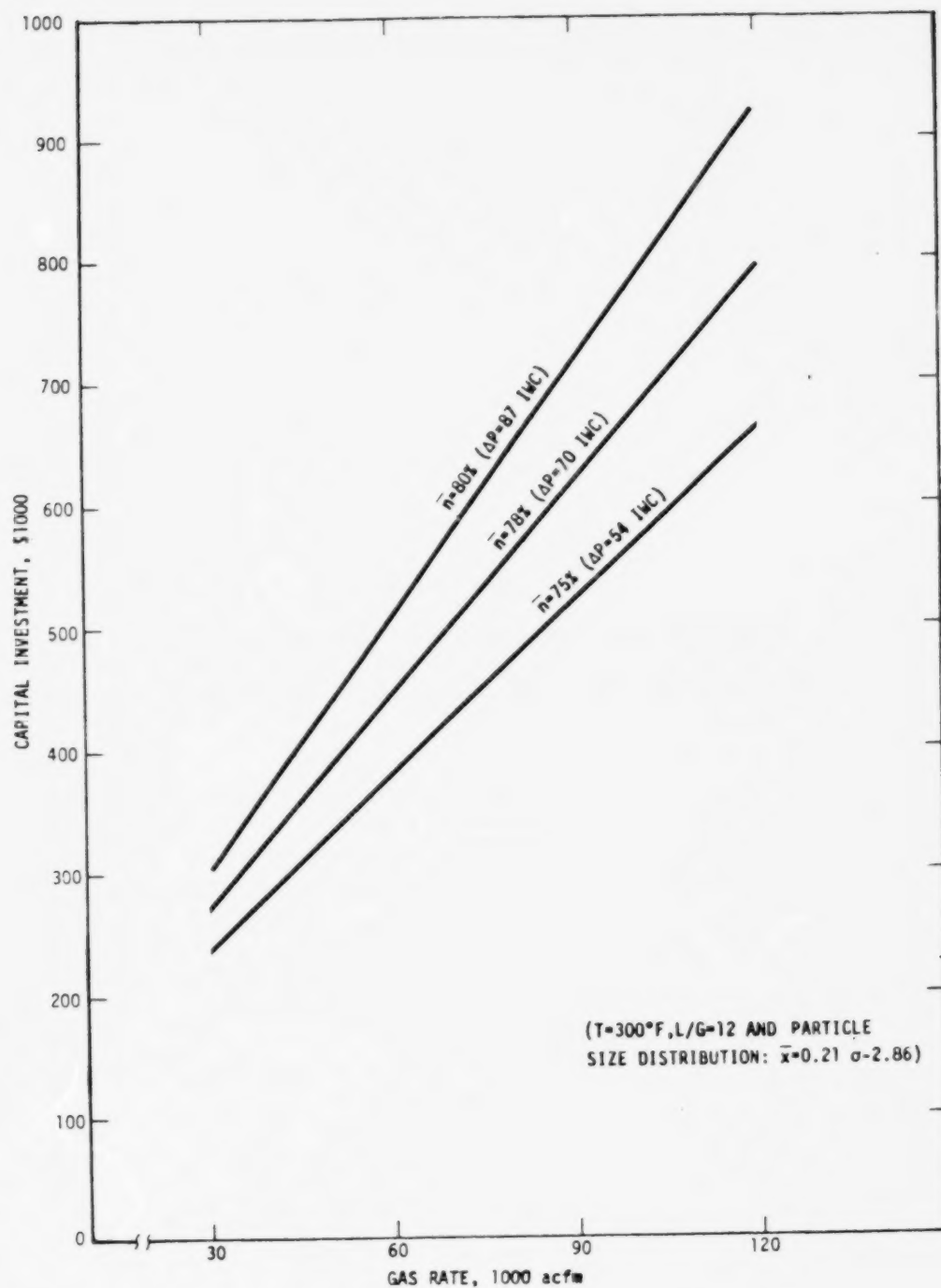


Figure B-4-1A. Effects of collection efficiency and gas rate on the capital investment of venturi scrubber systems for open hearth furnace gas.

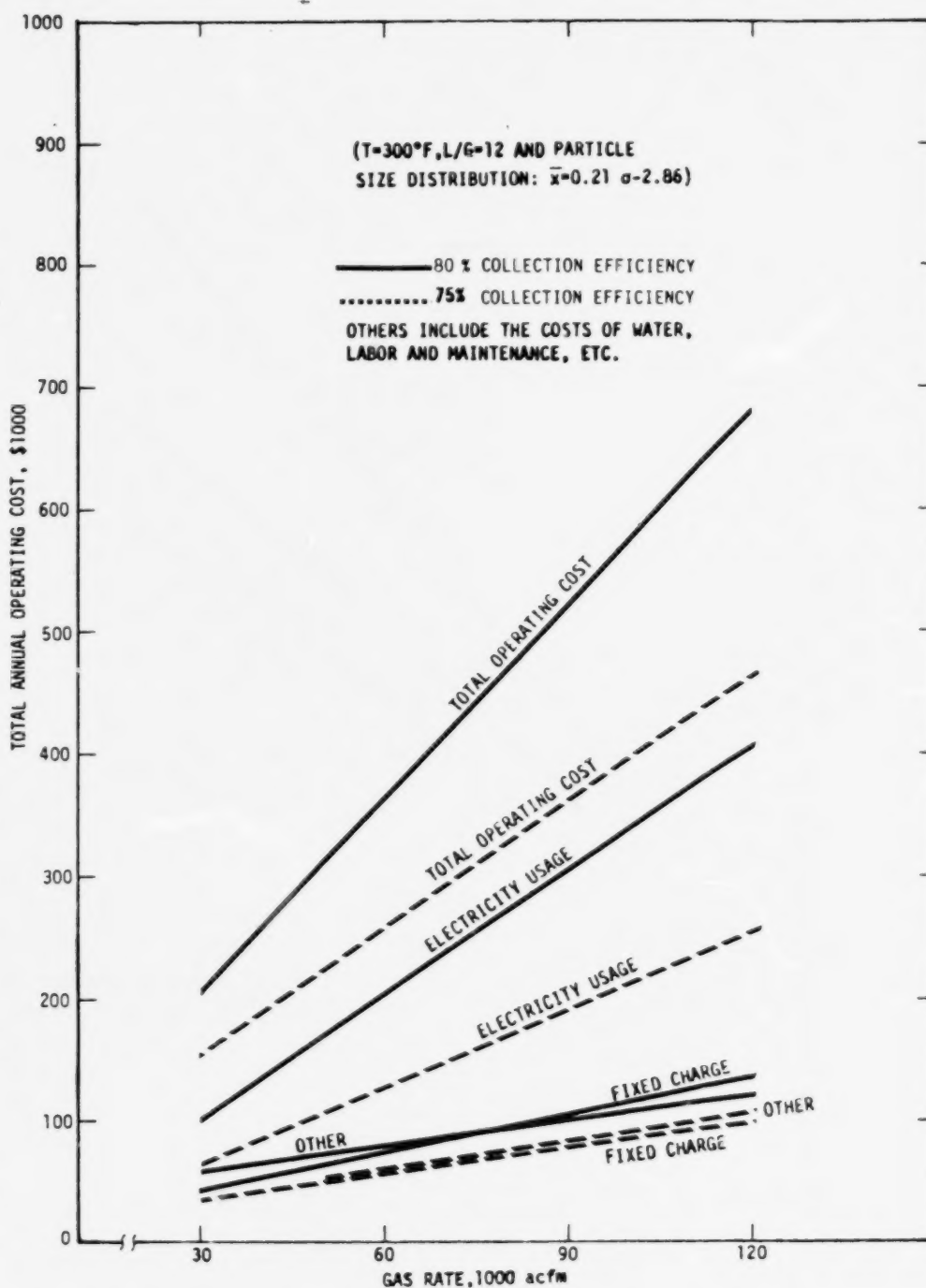


Figure B-4-1B. Effects of gas rate, electricity usage, fixed charge and others on the annual operating cost of venturi scrubber systems for open hearth furnace gas.

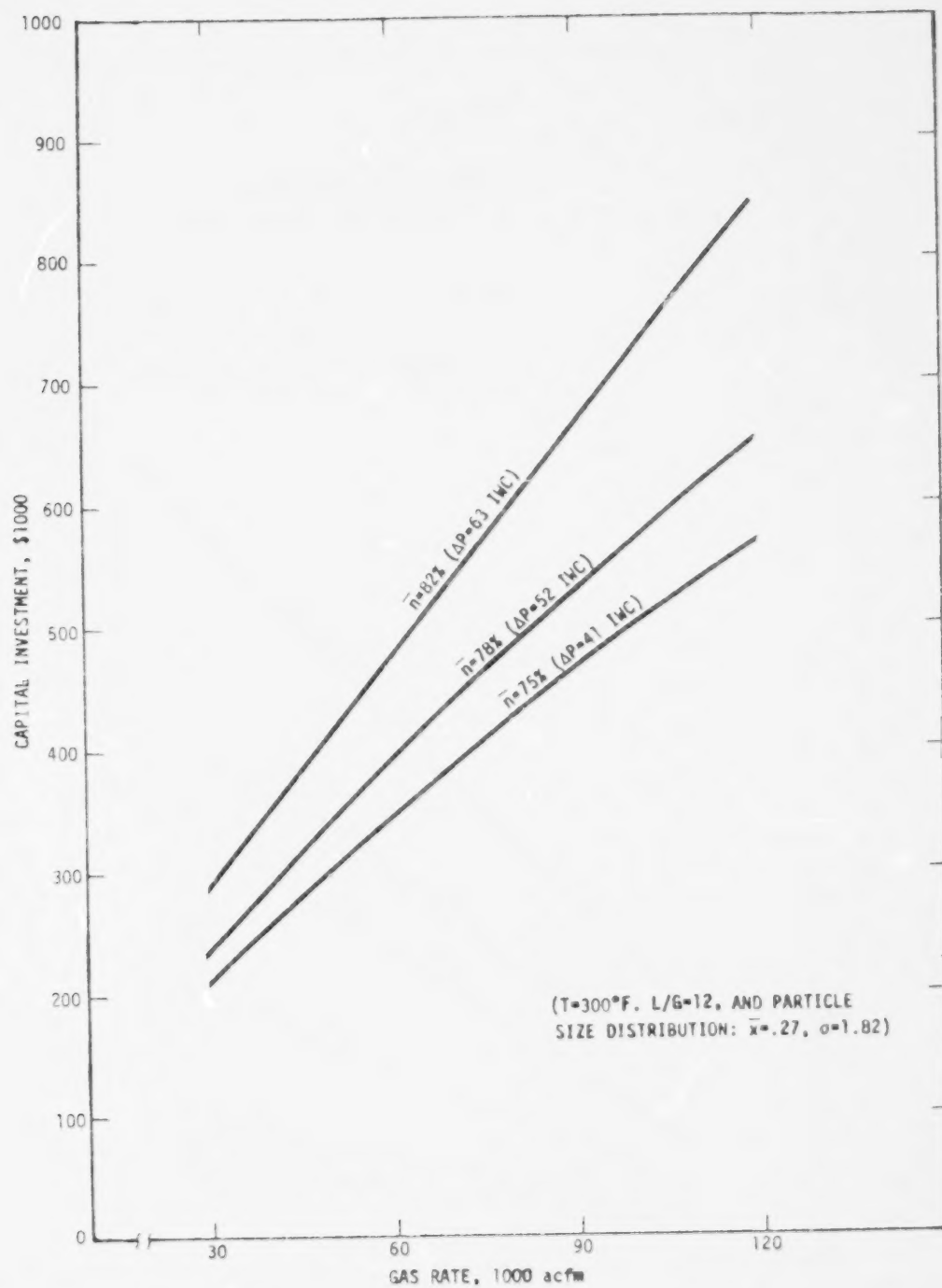


Figure B-4-2A. Effects of collection efficiency gas rate on the capital investment of venturi scrubber systems for basic oxygen furnace gas.

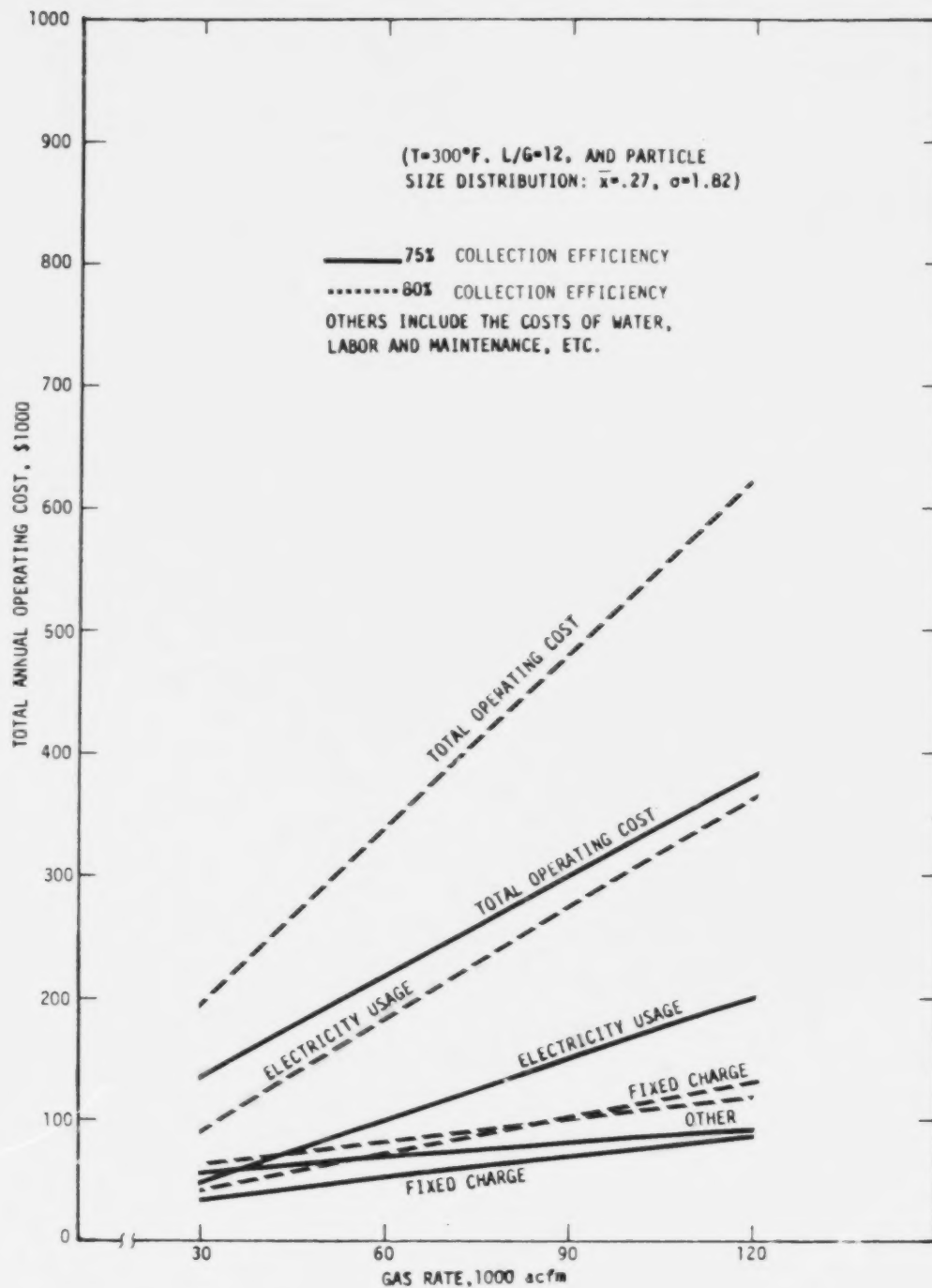


Figure B-4-2B. Effects of gas rate, electricity usage, fixed charges and others on the annual operating cost of venturi scrubber systems for basic oxygen furnace gas.

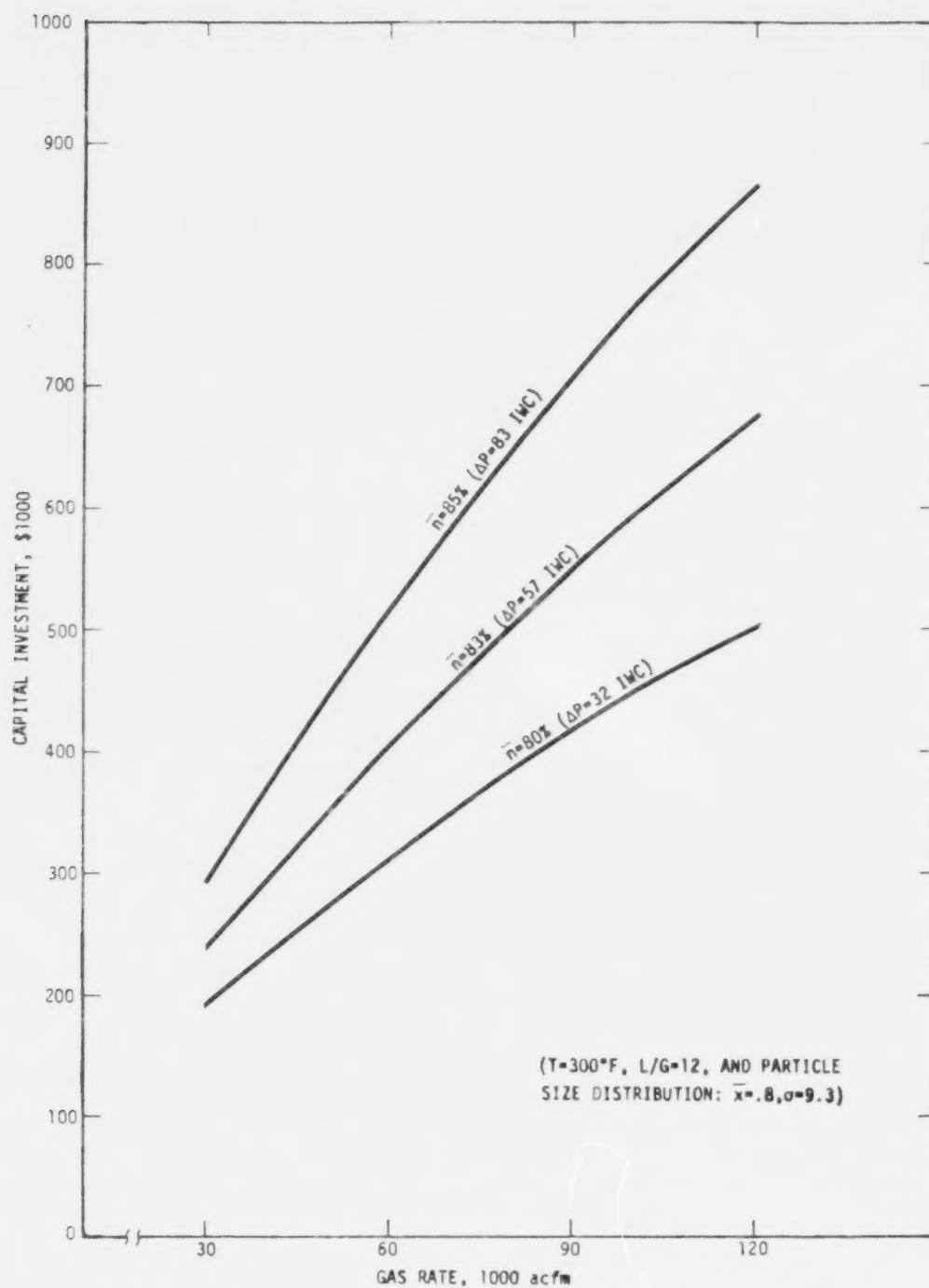


Figure B-4-3A. Effects of collection efficiency and gas rate on the capital investment of venturi scrubber systems for electric arc furnace gas.

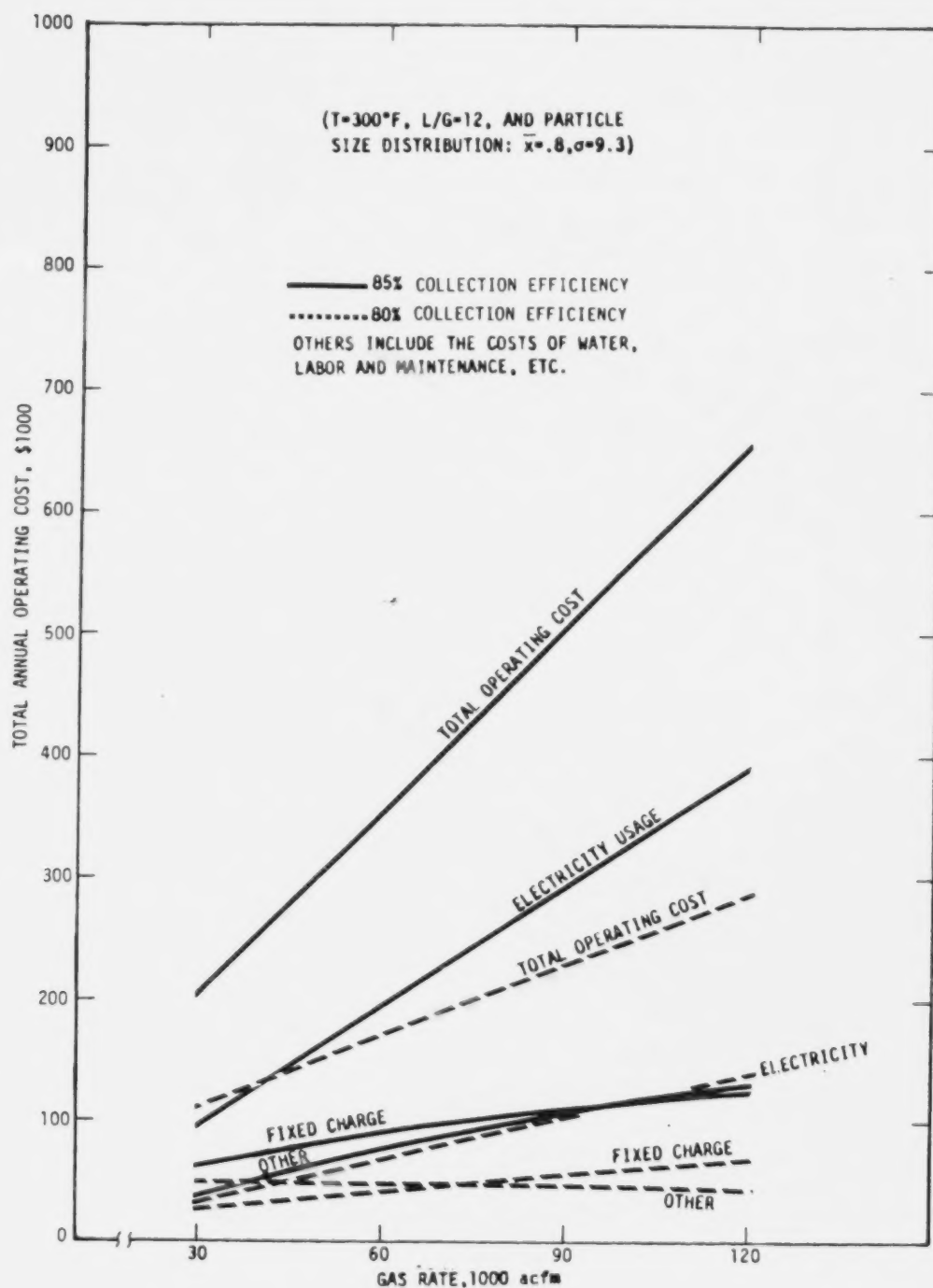


Figure B-4-3B. Effects of gas rate, electricity, fixed charge and others on the annual operating cost of venturi systems for electric arc furnace gas.

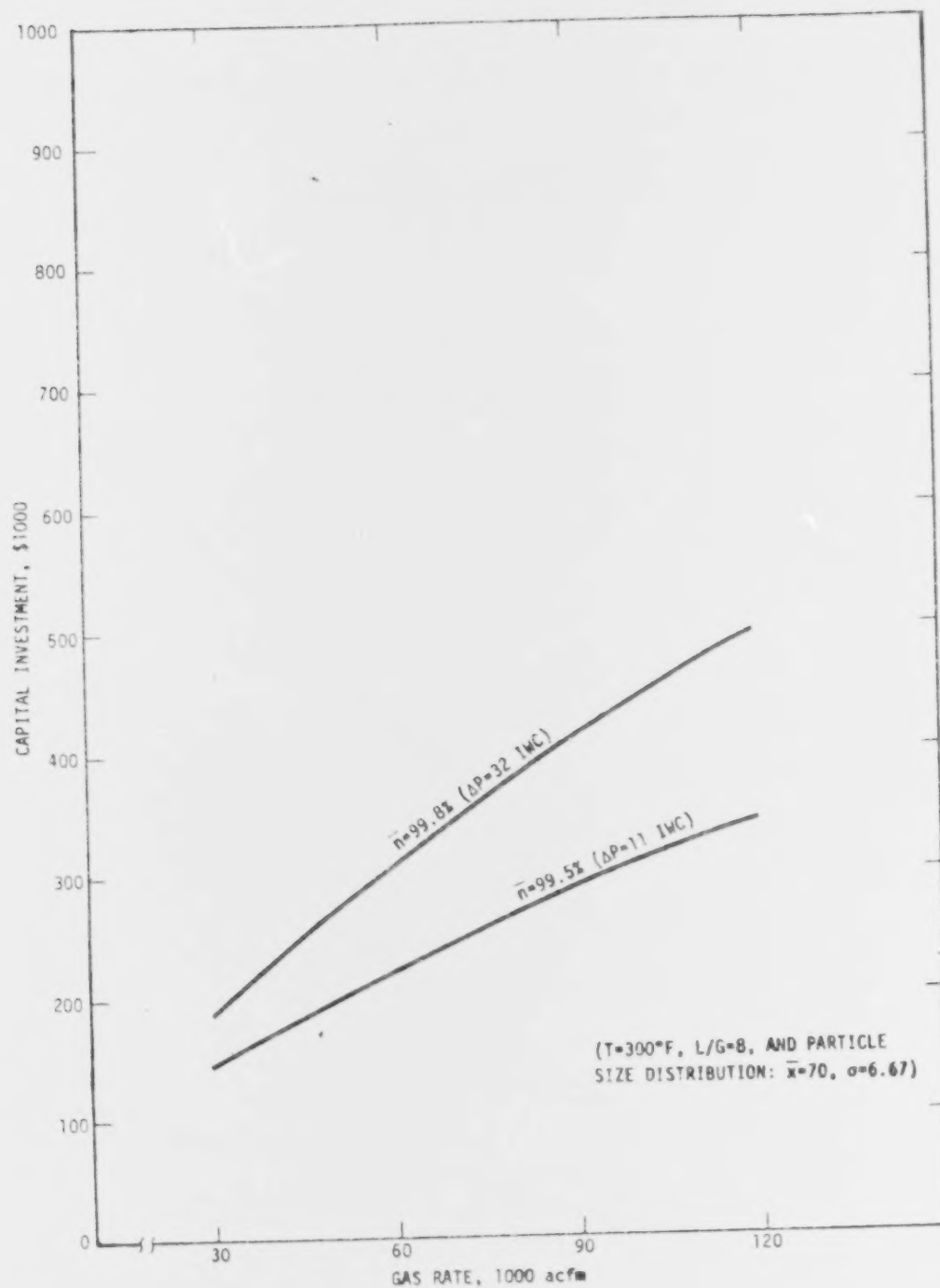


Figure B-4-4A. Effects of collection efficiency and gas rate on the capital investment of venturi scrubber systems for sintering machine gas.

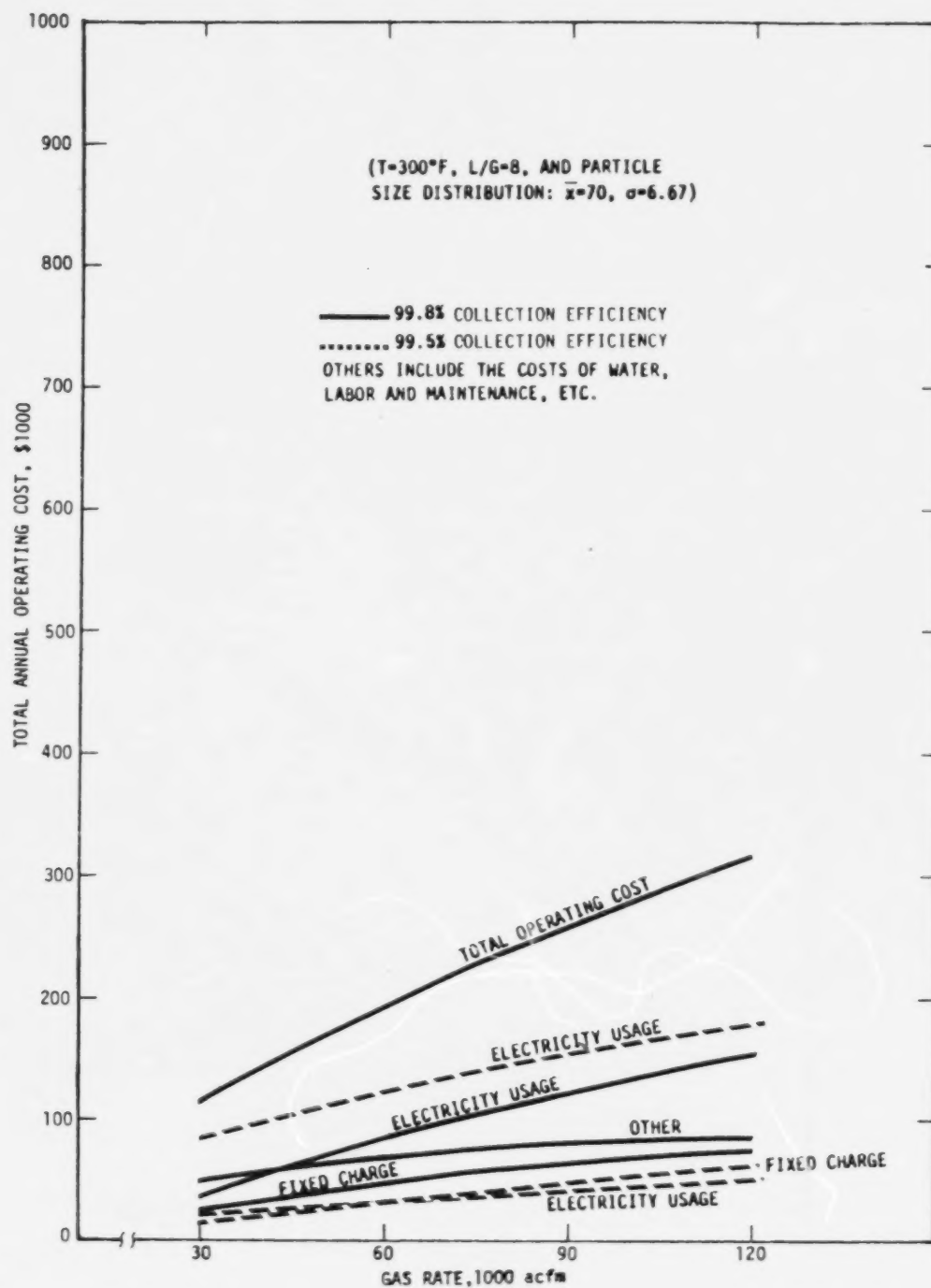


Figure B-4-4B. Effects of gas rate, electricity usage, fixed charge and others on the annual operating cost of venturi scrubber systems for sintering machine gas.

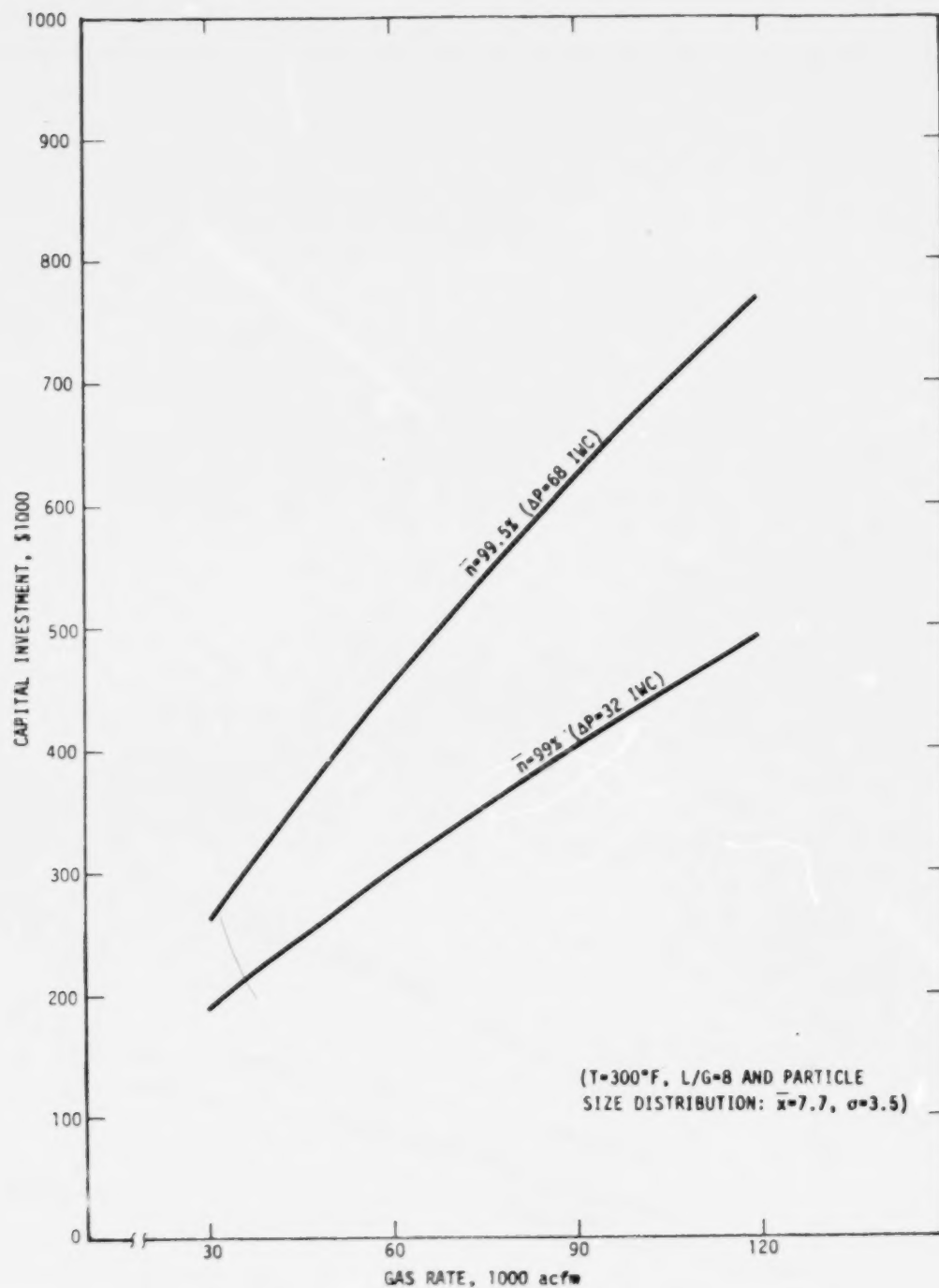


Figure B-4-5A. Effects of collection efficiency and gas rate on the capital investment of venturi scrubber systems for sintering machine gas pretreated with mechanical collector.

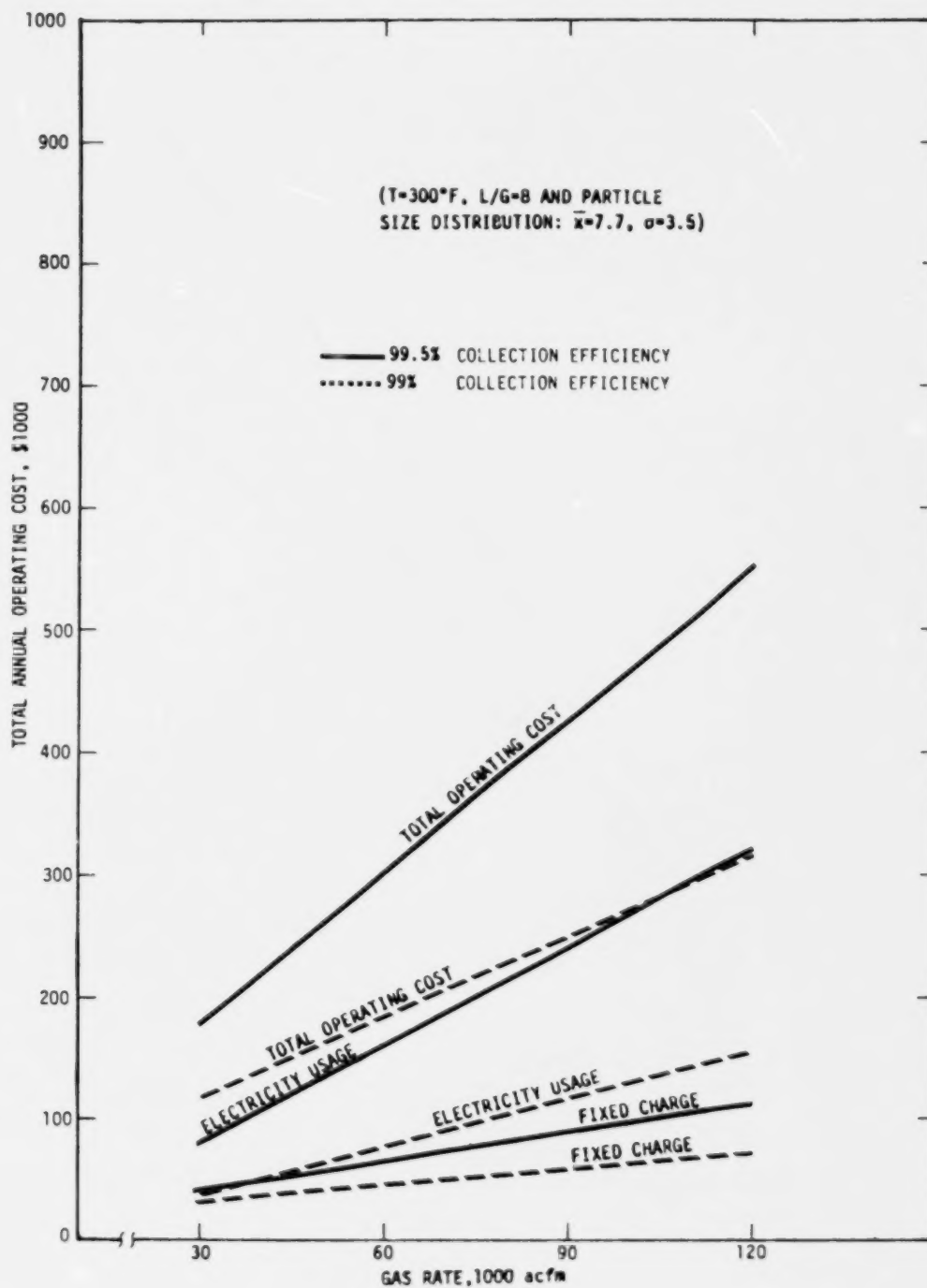


Figure B-4-5B. Effects of gas rate, electricity usage, fixed charge and others on the annual operating cost of venturi scrubber systems for sintering machine gas pretreated with mechanical collector.

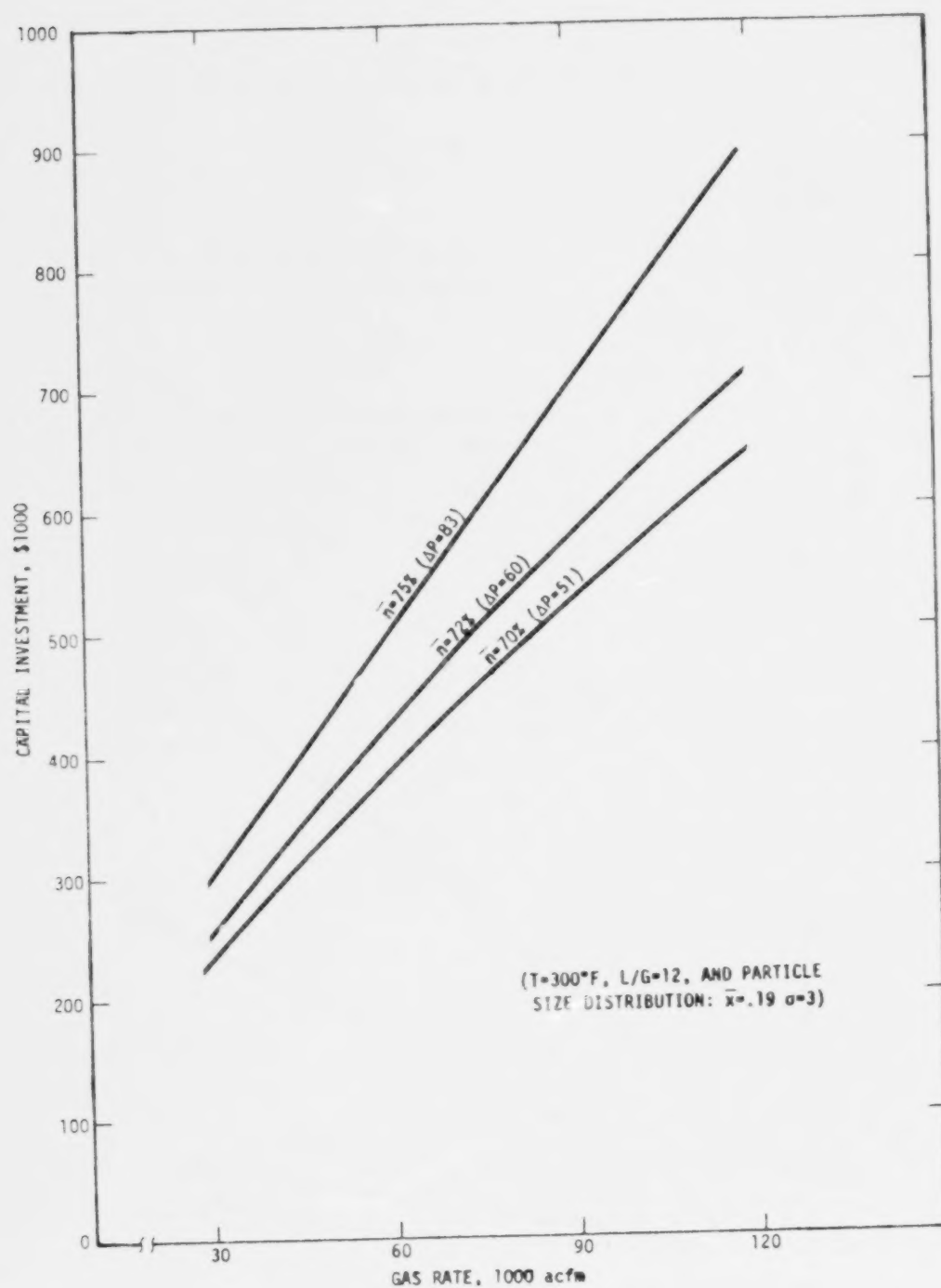


Figure B-4-6A. Effects of collection efficiency and gas rate on the capital investment of venturi scrubber systems for ferro-silicon and arc furnace gas.

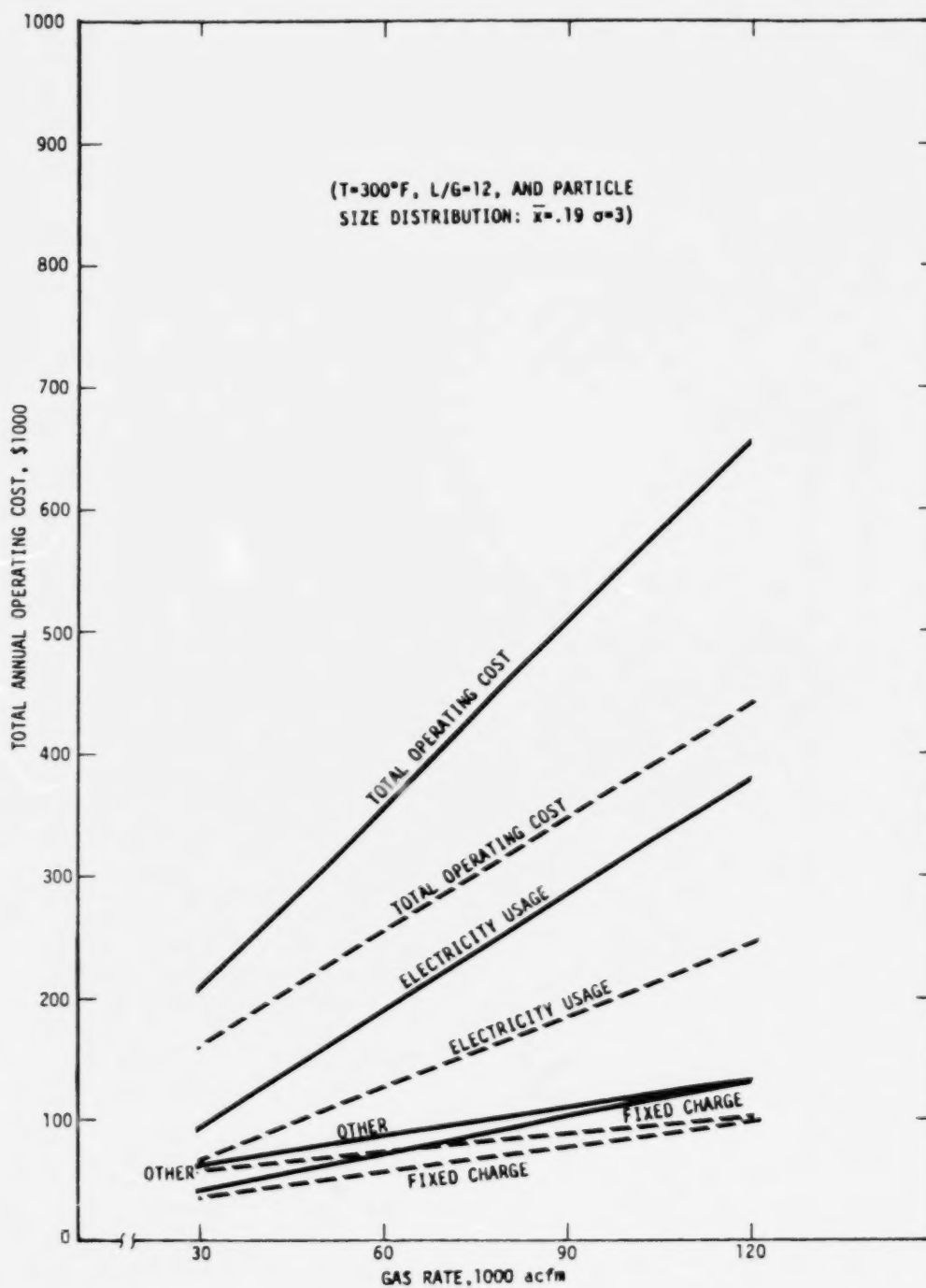


Figure B-4-6B. Effects of gas rate, electricity usage, fixed charge and others on the annual operating cost of venturi scrubber systems for ferrosilicon arc furnace gas.

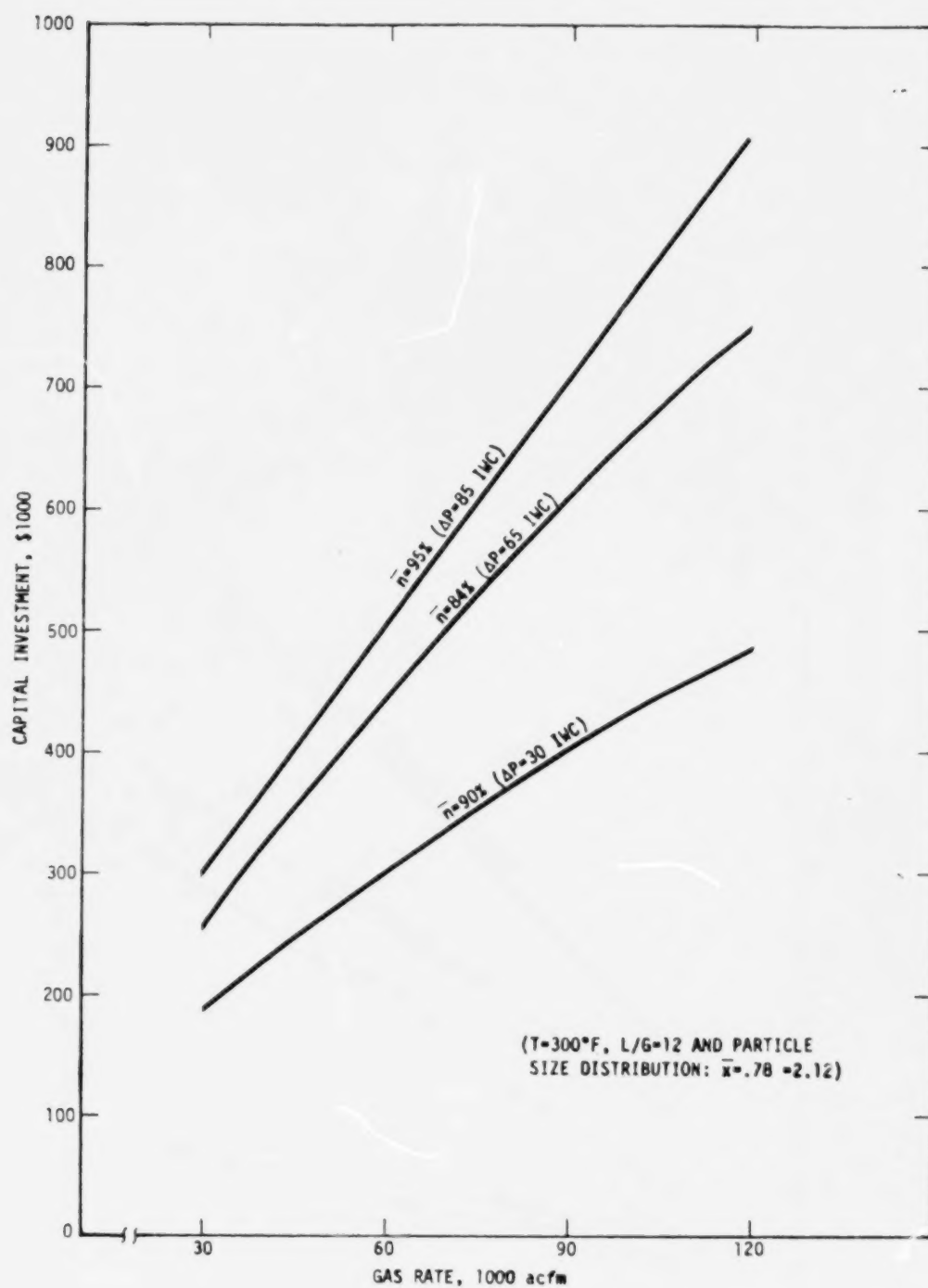


Figure B-4-7A. Effects of collection efficiency and gas rate on the capital investment of venturi scrubber system for ferromanganese arc furnaces.

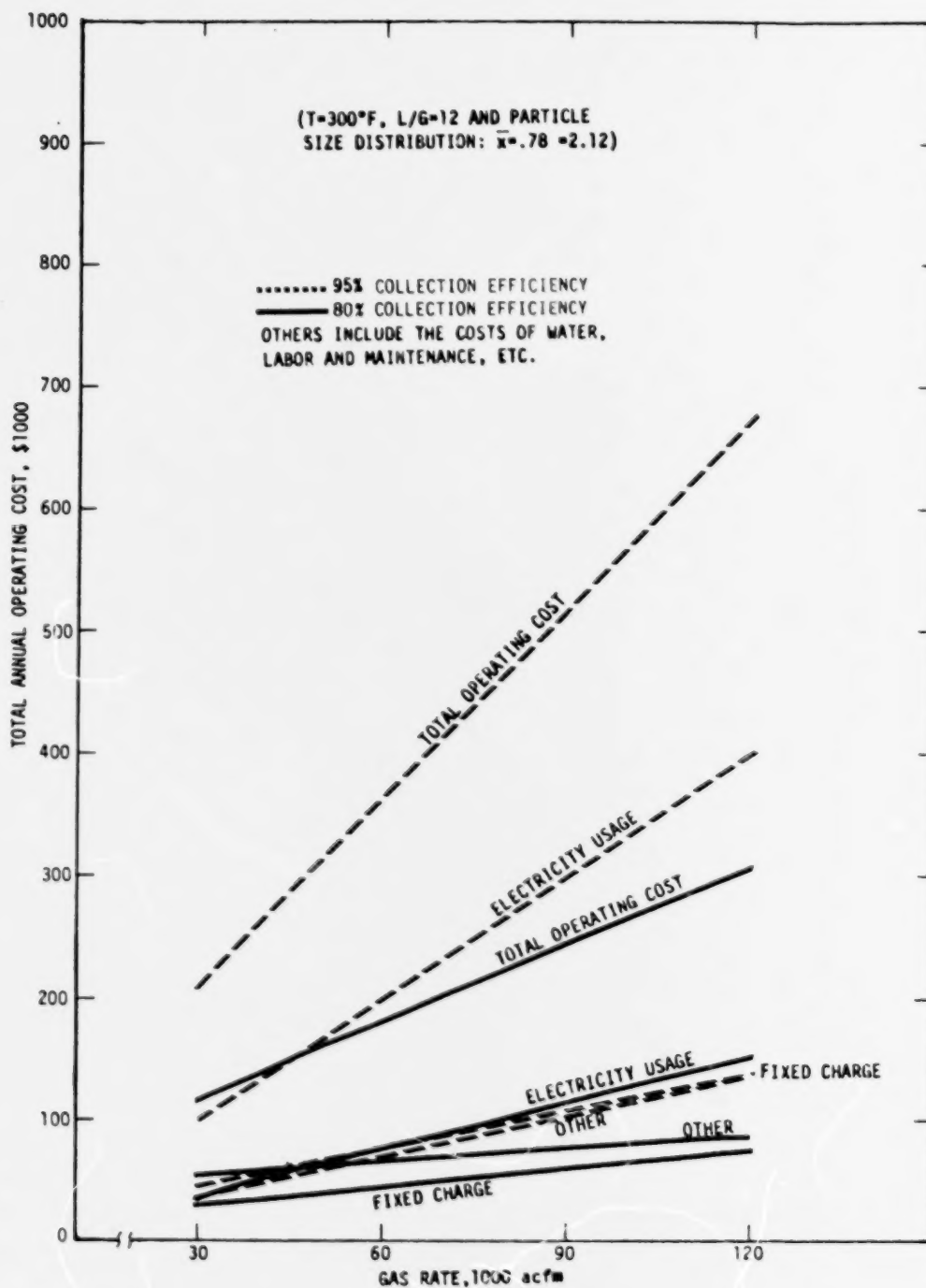


Figure B-4-7B. Effects of gas rate, electricity charge, fixed charge, and others on the annual operating cost of venturi scrubber systems for ferromanganese arc furnace gas.

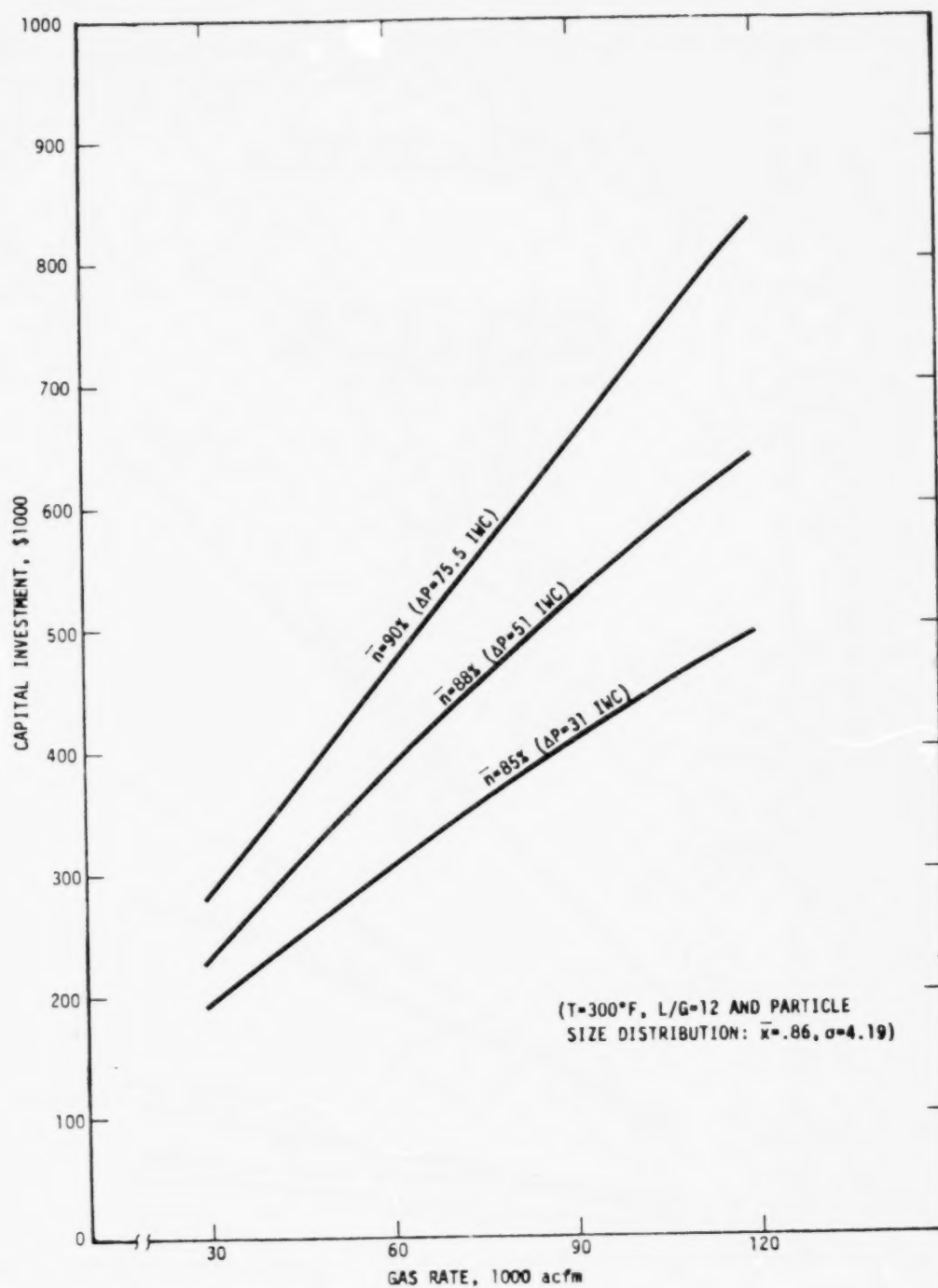


Figure B-4-8A. Effects of collection efficiency and gas rate on the capital investment of venturi scrubber systems for ferrochromium arc furnace.

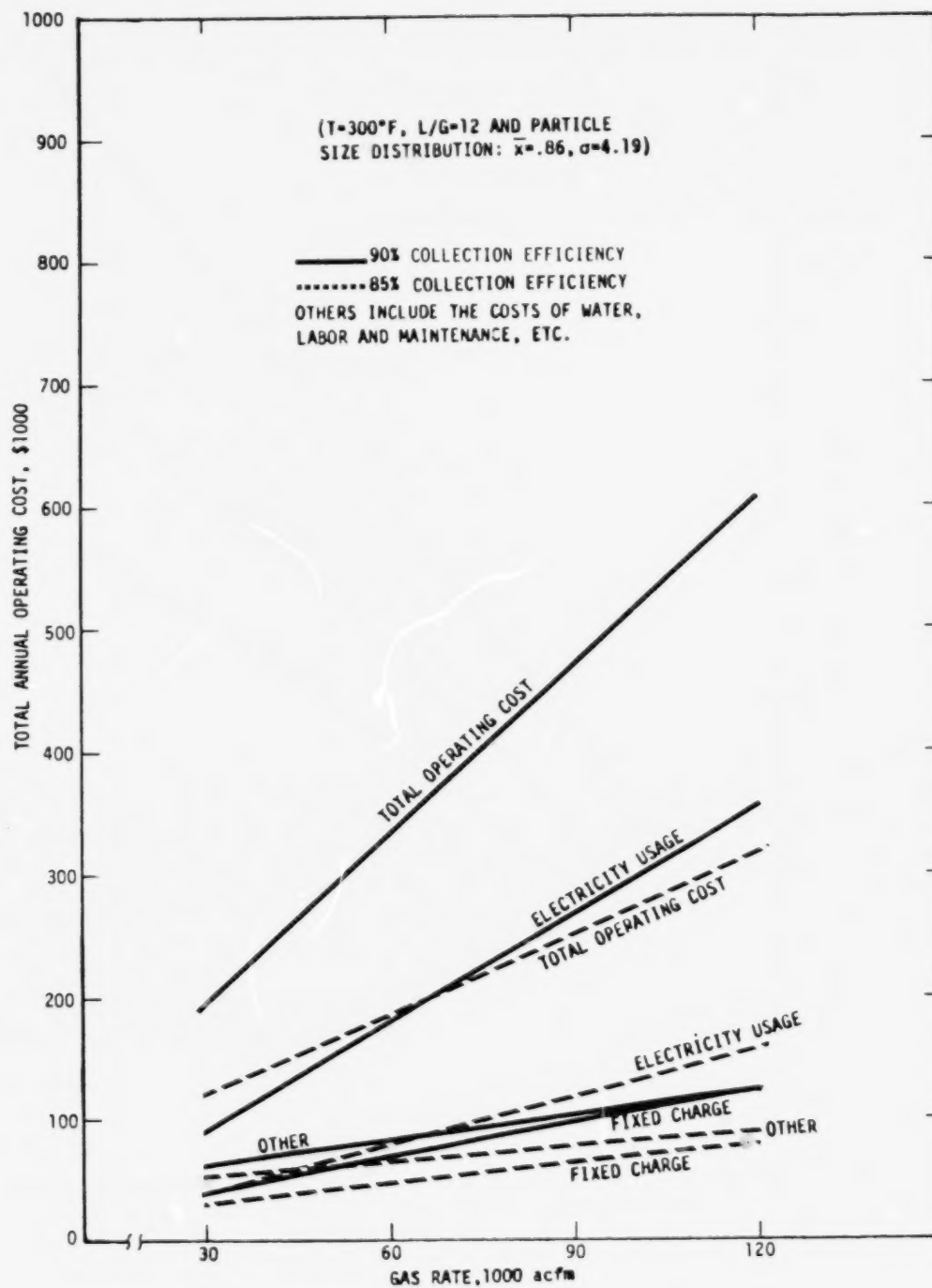


Figure B-4-8B. Effects of gas rate, electricity usage, fixed charge and others on the annual operating cost of venturi scrubber systems for ferrochromium arc.

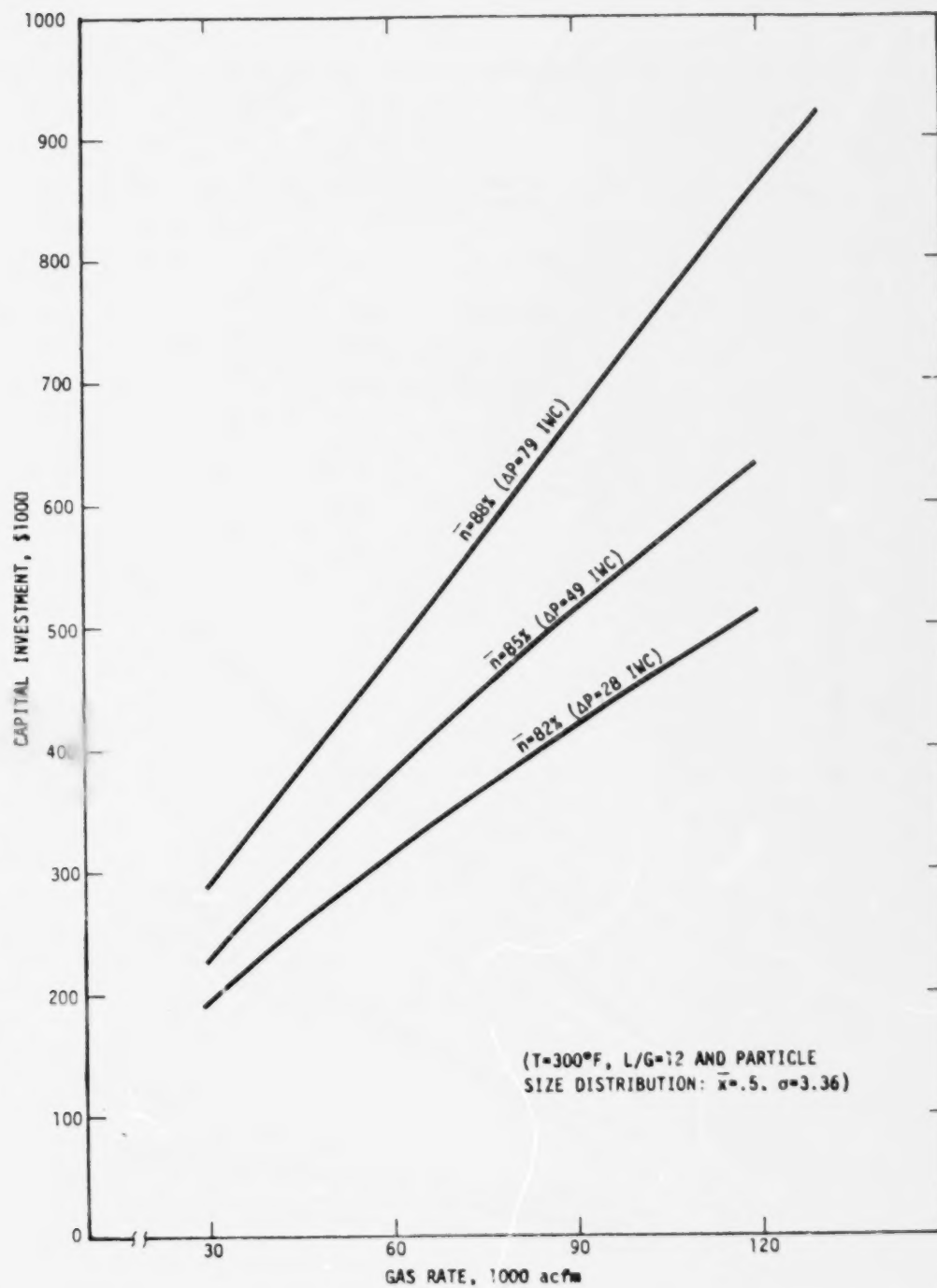


Figure B-4-9A. Effects of collection efficiency and gas rate on the capital investment of venturi scrubber systems for miscellaneous ferroalloy arc furnace.

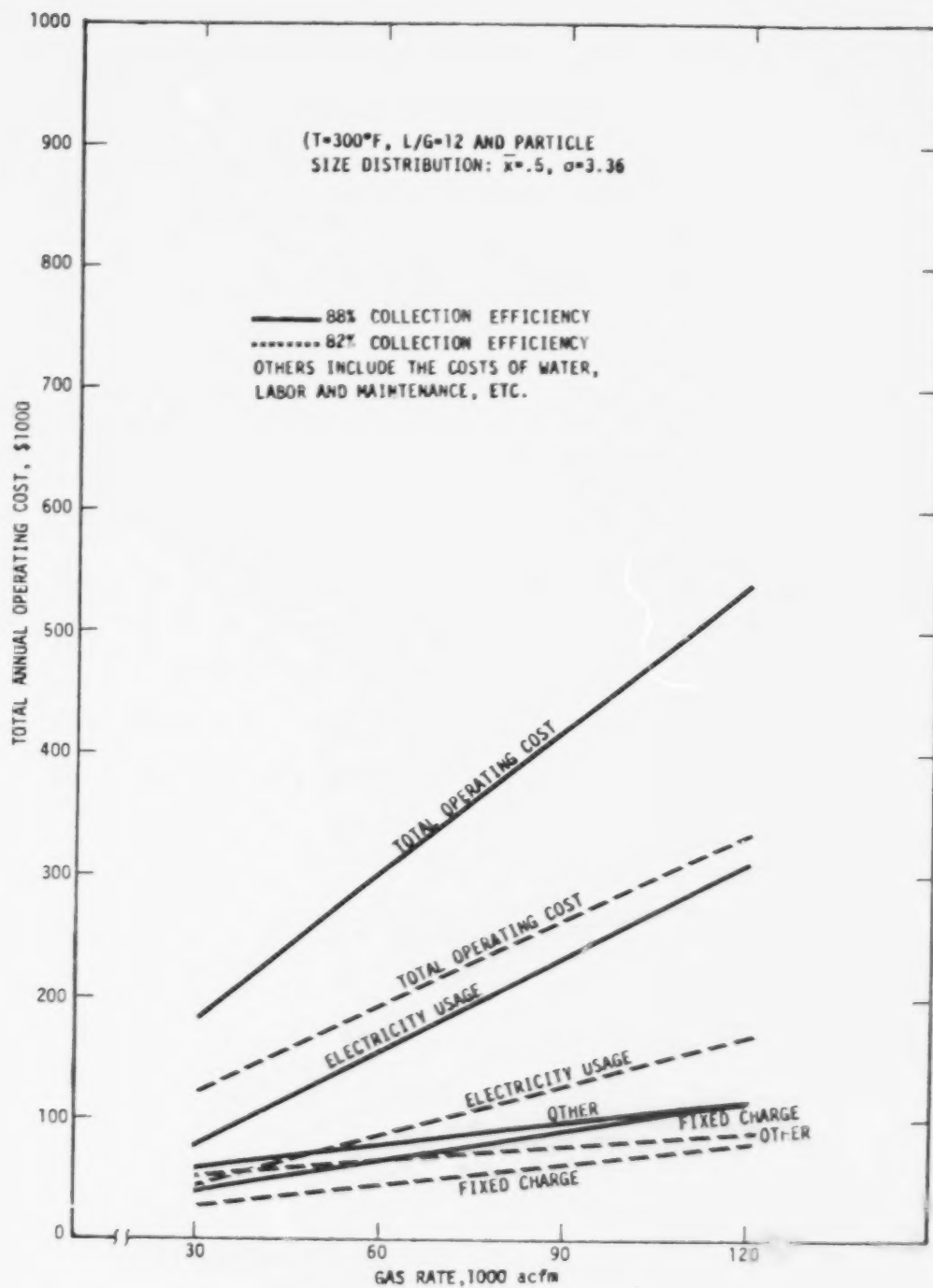


Figure B-4-9B. Effects of gas rate, electricity usage, fixed charge and others on the annual operating cost of venturi scrubber systems for miscellaneous ferroalloy arc furnace.

APPENDIX B-5

CASE HISTORY OF A USER'S EXPERIENCE WITH A LARGE FABRIC FILTRATION SYSTEM

This appendix is a case history of a fabric filter system on a typical application in the iron and steel industry. The plant is a midwestern electric arc furnace steel shop. The information contained herein was obtained during a site visit and conversations with engineering, operating and maintenance personnel.

The melt shop is a complex consisting of a six-strand continuous casting unit and three primary aisles: a scrap aisle, furnace aisle, and teeming aisle. The structure is 420 ft long, 250 ft wide, and 152 ft high. An attached servicing facility adds another 180 ft in length and 120 ft in width.

Six cranes service the shop: a 300-ton ladle crane and 25-ton maintenance crane service the teeming aisle, a 150-ton and a 25-ton crane service the furnace aisle, and two 25-ton cranes service the scrap aisle.

The plant operates two identical 225-ton capacity 24 ft diameter electric arc furnaces powered by a 76,000 kVA

transformer. Each carbon electrode is 24 in. in diameter, 8 ft long, weighs 2700 lb and costs \$1,900. Each furnace weighs 480 tons empty and can be tilted 15 degrees to pour off slag and 40 degrees for tapping the 225 ton heat. The normal time from initial scrap charging to pouring is approximately 4 h. The molten steel from the furnaces is either fed to the continuous casting machine or teemed into molds. If the steel is teemed, 50 to 60 3-1/2 ton ingots are obtained from each heat; if the steel is cast, it is cast into blooms 7 in. X 7 in. X 30 ft in length.

Scrap charges consist basically of low grade scrap--No. 2 bundles with galvanized, auto shredder scrap, and oily turnings. Maximum amount of turnings allowed is 20 percent of the total charge (5% oil content) or two 10-ton buckets which are always charged first. Very little fluorspar flux is used in the melt. Each furnace heat lasts slightly under 4 h and consists of three charges (one primary and two back charges). Oxygen lancing is used to burn out the door and lower carbon content. Occasionally, oxygen lancing will be used to hype up the melt rate if production is lagging behind continuous casting demands. This increases the dust emission rate from the furnaces. The refining period encompasses the final 0.5 h of the heat. Normal production is 12 to 13 heats per day (200 to 225 tons each).

The original air pollution control system was purchased with the furnaces and was started up in 1965. This system was the direct furnace evacuation type. One of the unique features of this system is the mounting of the water-cooled fume take-off duct or elbow on the furnace. Originally, the elbow was to mount on the furnace roof support beams. Two 10-in. and two 4-in. pipe lines (water supply and return) would also have to be mounted on the beams. Because of the additional weight introduced in this fashion, a tilt elbow was used whereby the elbow and associated piping mounts directly to the furnace platform. Tilting onto or off of the roof is accomplished through a hydraulic cylinder at 2,000 psi. The elbow is normally on the furnace during melting, slagging and pouring, and off the furnace for charging.

The total exhaust volume of 220,000 acfm at 500°F from the two furnaces was handled by an open pressure baghouse. The baghouse had 144,200 ft² of total filtration area divided into 14 compartments for a net operating air to cloth ratio of 1.78:1. Two compartments were off line for reverse air cleaning. The bags were 11-3/4 in. diameter X 30 ft 7 in. long fiberglass with a silicon/graphite finish.

This \$3,000,000 system never operated properly. The 2500°F furnace off gas required cooling to keep the tempera-

ture at or below 500°F. The cooling was done by spraying water directly into the ductwork located above the charging aisle craneway. The material buildup inside the ductwork due to this cooling method eventually caused structural failure and required supporting the ductwork with cables from the roof trusses. The original baghouse system was badly undersized (reasons for this are unclear), and this resulted in a reduction of melt capacity to 75 ton/h for both furnaces.

Dissatisfaction with the existing system and realization that direct evacuation control systems should be supplemented with canopy exhaust prompted management to make extensive modifications to the system which were completed in 1974.

The old direct evacuation control system was kept intact (with the exception of the water spray system), and a new baghouse was added in parallel. In addition, canopy hoods are installed over each furnace and tapping location. During meltdown and refining, gases are removed to the baghouses through the tilt elbow. During charging with the roof off, gases are collected in the canopy (approximately 100 ft X 70 ft) over each furnace. The hood damper automatically opens through limit switches when the roof is raised and swung off. The total exhaust volume is now 1,326,612 acfm at 275°F.

The baghouse addition consists of a 16-compartment open pressure baghouse with 23,847 ft² of polyester bags per compartment. The system, as a whole, now operates at 2.7:1 net air to cloth ratio with one old compartment and one new compartment down for cleaning.

For bag cleaning, one compartment in one new unit and one compartment in one old unit are simultaneously off line. Thus, only two compartments out of the total system of two baghouses are being cleaned at any one time. Cleaning is accomplished on a continuous basis. A compartment cleaning cycle consists of:

1. 29 s reverse air,
2. 40 s null (settle),
3. 29 s reverse air,
4. 40 s null (settle),
5. 22 s repressure, and
6. Next compartment.

The emission limitation for the shop is 39.5 lb/h based on the State Process Weight Rule. The company has estimated the amount of dust not collected by the baghouses with Hi-Vol samplers positioned in the roof monitor area above the canopy hoods and with samplers in the baghouse monitors to determine emission concentrations. Total uncontrolled emissions were thus estimated to be 6 to 20 lb/h. Dust

collected by the baghouses ranges from 30 to 45 lb/ton of steel produced, resulting in 3150 lb/h to 4725 lb/h (at a production rate of 105 ton/h). The bulk density of the collected dust is about 75 lb/ft³.

The operating experience with the new modified system has been satisfactory. One man working 5 days per week is responsible for inspection of baghouse compartments and related equipment. The total cost to the company for this man is \$17,000/year. For bag replacement and other repairs, men are drawn from the general maintenance pool. The company estimates a total operating and maintenance cost of \$1.20/ton of steel produced.

Problems were initially encountered with the canopy damper-operators. The actuator arms were breaking or shearing keys in the gearing in the drive units. These drive units were rated at 590 ft-lb torque. The torque required to operate the dampers was 1600 ft-lb at times. Today, the operators are rated at 2200 ft-lb and the problem no longer exists.

Problems occurred with the vertical poppet damper guides shortly after start-up of the new system. The original guides were made of brass and quickly became worn resulting in the dampers sticking during operation. The old guides were replaced with new steel guides and the problem was alleviated.

The collected dust falls into a trough hopper. An auger in the bottom of the hopper runs continuously, conveying the dust to a discharge auger which conveys the dust to the end of the baghouse, where it is discharged into a covered pan. Then the pan is full, the conveyors are shut down and the pan is picked up and dumped. A clean pan is inserted and the conveyors are restarted.

Zero-speed switches on the conveyors preclude packing dust into a section which is inoperative and finally jams the complete system. When a section of conveyor ceases to operate, all augers upstream stop. This negates the necessity of removing covers, augers, etc., to unpack a conveyor system.

Maintenance problems have not plagued the screw conveyors except for the outboard bearings. These were not packed well enough, allowing dust to enter; the shafts eroded from 1-1/2 in. diameter to 1-3/4 in. diameter. This problem was solved by improving the packing to keep dust out.

The company reports that hoppers must be rapped with a wooden mallet periodically to dislodge bridged dust. They investigated installing a mechanical rapping system, but decided it was too costly.

Only 119 bags have been changed since 1974, according to maintenance personnel. Bags are changed only as they fail. Disposable bag caps are not being used. If a bag is replaced, the top cap as well as top and bottom clamps are reused. There have been only five to six failures due to abrasion around the support rings. Most problems occur near the bag bottoms where the dust enters. The baghouses are continuing to experience a buildup of dust in the thimbles at the cell plate wherein the bag entrance becomes constricted, thus, increasing the pressure drop slightly. It is easy to dislodge this buildup with a screwdriver or similar tool, but no permanent solution has been found, even with the equipment manufacturer studying the problem.

Stainless steel screw-type clamps are used and bags are tensioned from 55 to 60 lb. Bag tension is checked every 3 months by the maintenance man. On both the new and the old baghouses, there are six rows of bags between walkways.

APPENDIX C-1
ELECTROSTATIC PRECIPITATOR SUBSYSTEM AND
COMPONENT FUNCTION AND OPERATION

Transformer-Rectifiers

The transformer-rectifier unit consists of a high-voltage transformer, high-voltage silicon rectifiers, and high-frequency choke coils. The unit converts the low-voltage alternating current to high-voltage unidirectional current suitable for energizing the precipitator.

The transformer, rectifiers, and choke coils are submerged in a tank filled with a dielectric fluid. The tank is equipped with high-voltage bushings, liquid level gauge, drain valve, ground lug, filling plug, lifting lugs, and surge arresters, which discharge to ground any harmful transients that appear across the d.c. metering circuit.

The electrical equipment described below is necessary to produce and control the high-voltage unidirectional electrifield required to energize an electrostatic precipitator: the transformer-rectifier and control unit provide a complete system for energizing with either half-wave or full-wave voltages. Not all precipitator installations incorporate all of these subcircuits, but most will have

many of them. Certain automatic procedures described here may be performed manually on some installations.

- 1) A subsystem that automatically maintains and limits line voltage to the high-voltage transformer, which is connected to the discharge wires.
- 2) Silicon controlled rectifiers (SCR's), which provide a wide range of precipitator current and voltage control.
- 3) A current-limiting reactor, which limits current surges during precipitator sparking.
- 4) Automatic restart to initiate system operation after a line voltage failure or temporary ground condition in the precipitator.
- 5) Overload protection for the high-voltage rectifiers.
- 6) Panels containing component modules.

The SCR power circuit, d.c. overload circuits, relays, control transformers, resistors, the main contactor, current transformer, and other components are mounted in the control cabinet and are completely accessible for servicing. Positive ventilation for the control unit is provided by an intake fan located near floor level. Ventilating air is exhausted through an opening (grill-protected) in the upper rear of the control unit.

The transformer enclosure is a square metal housing bolted to the top of the transformer tank. The enclosure protects the transformer bushings and electrical connections from weather and also ensures, by means of a key interlock system, that none of the electrical connections or bushings

can be handled until the associated control cabinet has been deenergized and grounded.

The transformer pipe and guard are used to feed the high-voltage output of the transformer-rectifier to the support bushings, which in turn are connected to the upper high-tension support frame, from which the discharge wires are suspended. Figures C-1-1 and C-1-2 illustrate rapper and insulator assemblies and their relationship to the rest of the precipitator system.

During normal operation, optimization of applied power to the precipitator is accomplished by automatic power controls, which vary the input voltage in response to a signal generated by the sparkover rate. Provisions are also included to make the circuit current sensitive to overload and to allow control in the event that spark level cannot be reached. Although the circuits may vary from one installation to another, many of the features described below are common. An SCR mainline control diagram (Figure C-1-3) illustrates operation of the system described below.

When the circuit breaker and control circuit on-off switch are closed, power flows through the current-limiting reactor, current transformer, and current signal transformer to the primary of the high-voltage transformer. The SCR's act as a variable impedance and control the flow of power in

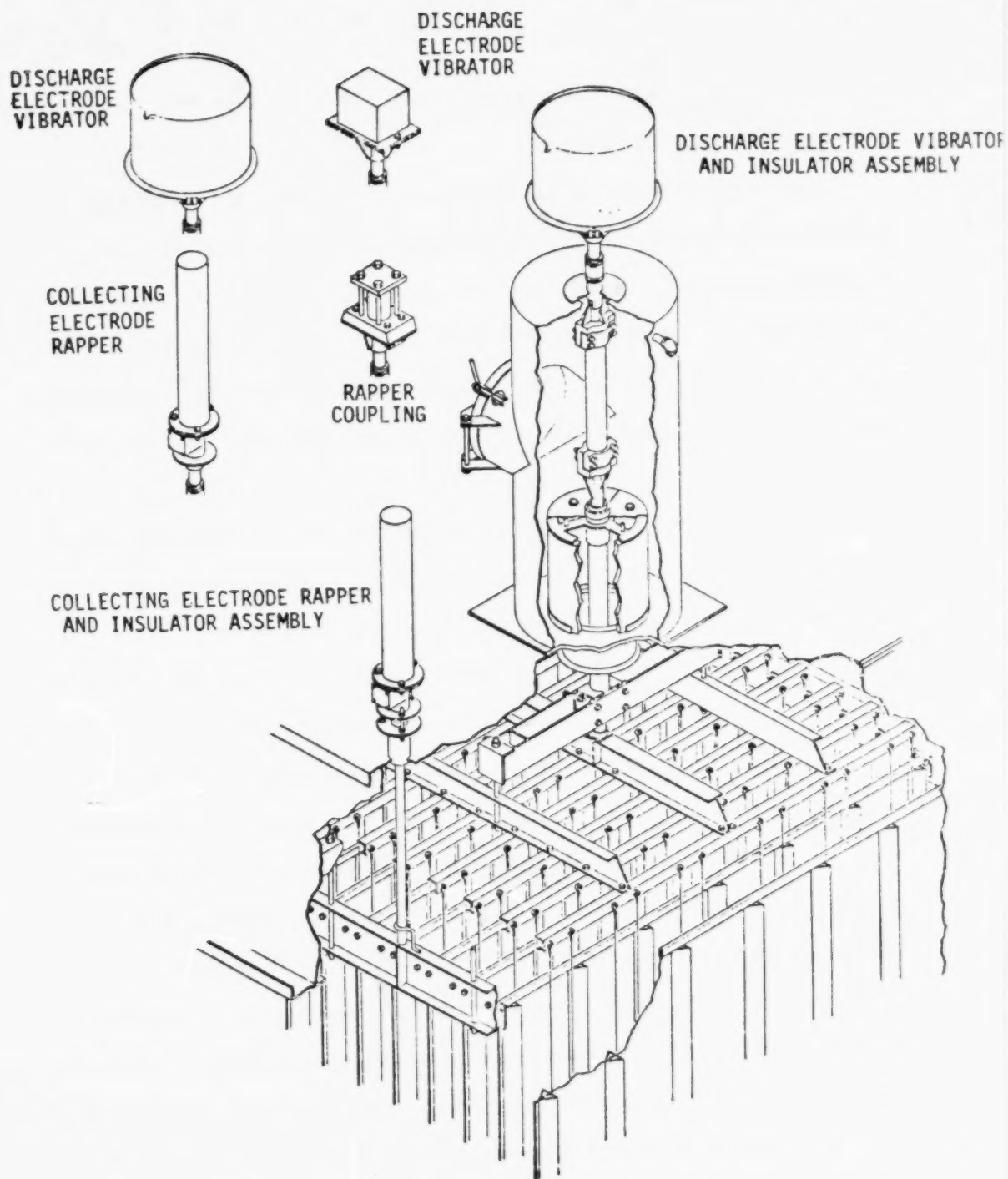


Figure C-1-1. Insulator, rapper assembly, and precipitator high-voltage frame.

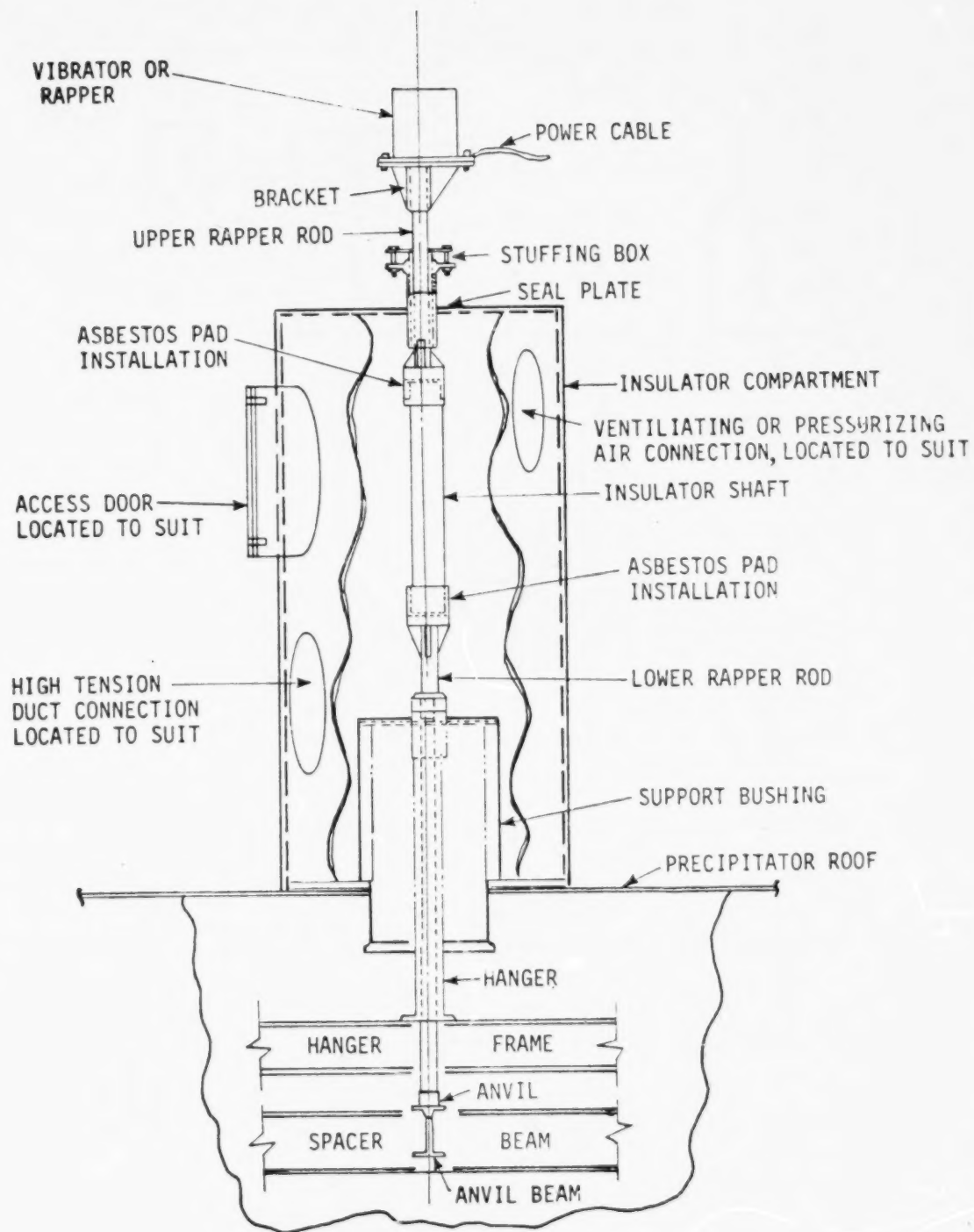


Figure C-1-2. Precipitator insulator and rapper assembly.

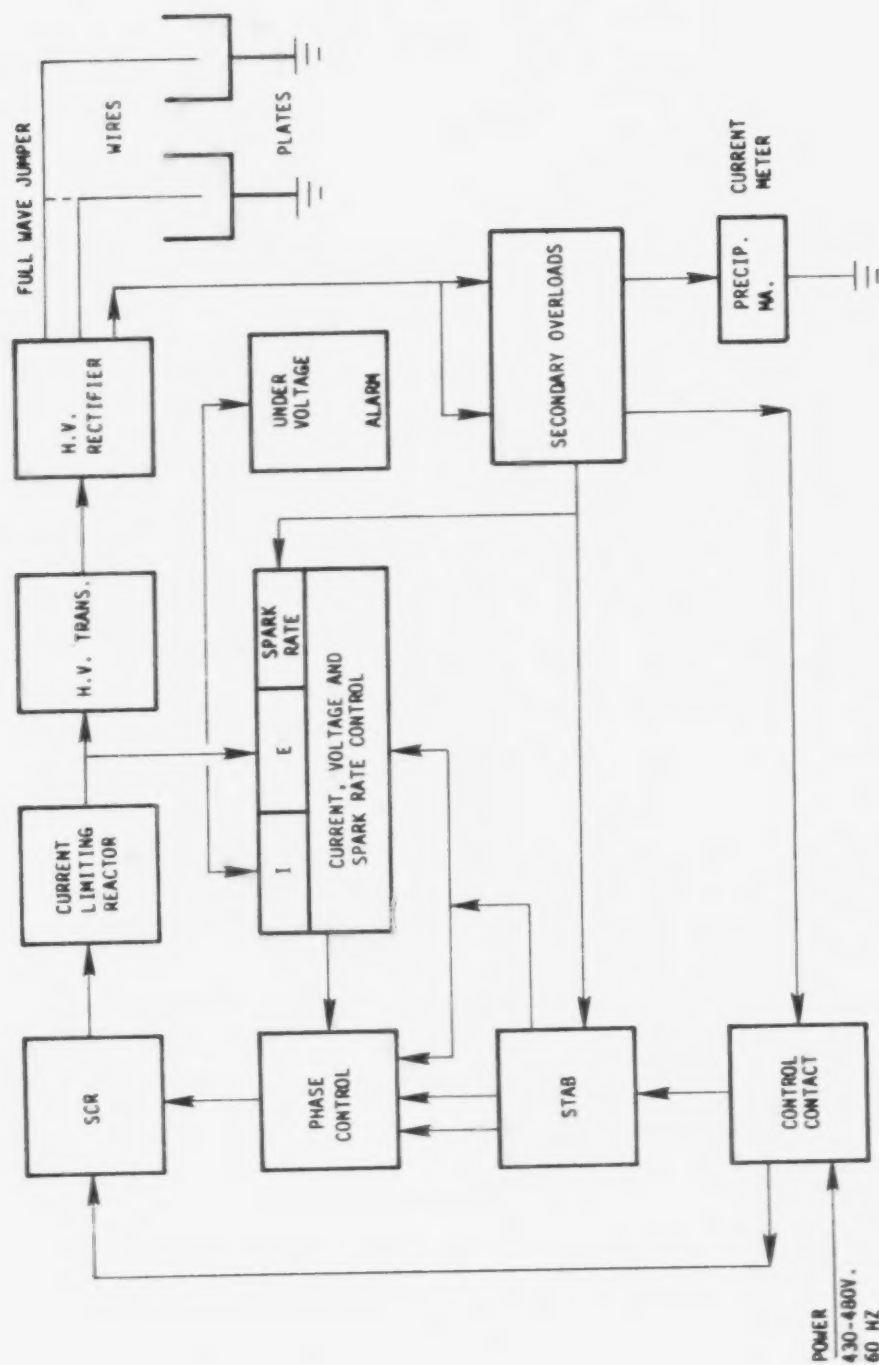


Figure C-1-3. SCR mainline control.

the circuit. An SCR is a three-junction semiconductor device that is normally an open circuit until an appropriate gate signal is applied to the gate terminal, at which time it rapidly switches to the conducting state. Its operation is equivalent to that of a thyatron. The amount of current that flows is controlled by the forward blocking ability of the SCR's. This blocking ability is determined by the firing pulse to the gate of the SCR. The current-limiting reactor reshapes the current waveform to essentially a sine wave and limits peak current associated with sparking.

The firing circuit module provides the proper phase-controlled signal to fire the SCR. The timing of the signal is controlled by (1) the potentiometer built in the module; (2) the signal received by the automatic controller; and (3) the signal received by the spark stabilizer.

The automatic control circuit performs three functions: spark control, current-limit control, and voltage-limit control.

Spark control is based on storing electrical pulses in a capacitor for each spark occurring in the precipitator. If the voltage of the capacitor exceeds the present reference, an error signal will phase the mainline SCR's back to a point where the sparking will stop. Usually this snap-action type of control will tend to overcorrect, resulting

in a longer downtime than is desirable. At low sparking rates, about 50 sparks per minute, the overcorrection is more pronounced, resulting in reduced voltage for a longer period, with subsequent loss of dust and reduced efficiency.

Proportional control is also based on storing of electrical pulses for each spark occurring in the precipitator. The phaseback of the mainline SCR's, however, is proportional to the number of sparks in the precipitator. The main advantage of proportional control over spark control is that the precipitator determines its own optimum spark rate, based on four factors: temperature of the gas, dust resistivity, dust concentration, and the internal condition of the precipitator. In summary, with proportional spark rate control, the precipitator determines the optimum operating parameters. With conventional spark control, the operator selects the operating parameters, which may not be optimal.

Some precipitators operate at the maximum voltage or current settings on the power supply with no sparking. In collection of low-resistivity dusts, where the electric field and the dust deposit are insufficient to initiate sparking, the no-spark condition may occur. The fact that the precipitator is not sparking does not necessarily mean that the unit is underpowered. It may have sufficient power to provide charging and electric fields without sparking.

The voltage-limit control feature of an automatic control module limits the primary voltage of the high-voltage transformer to its designated rating. A transformer across the primary supplies a voltage signal that is compared with the setting of the voltage control, as in the case of the current limit. The voltage control setting is adjusted to the primary voltage rating of the high-voltage transformer. When the primary voltage exceeds this value, a signal is generated that retards the firing pulse of the firing module and brings the primary voltage back to the control setting.

For current-limit control, a transformer in the primary circuit of the high-voltage transformer monitors the primary current. The voltage from this transformer is compared with the setting of current control, which in turn is adjusted to the rating of the transformer-rectifier unit. If the primary current exceeds the unit's rating, a signal is generated, as with spark control, which retards the firing pulse of the firing circuit, and this brings the current back to the current-limit setting.

With all three control functions properly adjusted, the control unit will energize the precipitator at its optimum or maximum level at all times. This level will be determined by conditions within the precipitator and will result

in any one of the three automatic control functions operating at its maximum, i.e., maximum voltage, maximum primary current, or maximum spark rate. Once one of the three maximum conditions is attained, the automatic control will prevent any further increase in power that would enable either of the other two control functions from reaching a second maximum value. If changes within the precipitator require it, the automatic control will switch from one maximum limit to another.

Other features include secondary overload circuits and an undervoltage trip capability, which are activated in the event that the voltage on the primary of the high-voltage transformer falls below a predetermined level and remains below that level for a certain period. A time-delay relay is also used to provide a delay period in the annunciator circuit while the network of contacts is changing position for circuit stabilization due to an undervoltage condition.

Rappers

The rapper equipment is a completely electrically operated system for the continuous removal of dust from the collecting plates. The system is composed of a number of magnetic-impulse, gravity-impact rappers that are periodically energized to rap the collecting plates for removal of dust deposits. The main components of the system are the rappers and the electrical controls.

The magnetic-impulse, gravity-impact rapper is a solenoid electromagnet consisting of a steel plunger surrounded by a concentric coil, both enclosed in a watertight steel case. The control unit contains all the components (except the rapper) needed to distribute and control the power to the rappers for optimum precipitation. The electrical controls provide a number of separate adjustments, so that all rappers can be assembled into a number of different groups, each of which can be independently adjusted from zero to maximum rapping intensity.

Some installations have mechanical rappers. In these installations each frame is rapped by one hammer assembly mounted on a shaft. A low-speed gear motor is linked to the hammer shaft by a drive insulator, fork, and linkage assembly. Rapping intensity is governed by the hammer weight, and rapping frequency by the speed of rotation of the shaft.

During normal operation, a short-duration d.c. pulse through the coil of the rapper supplies the energy to move the steel plunger. The plunger is raised by the magnetic field of the coil and then is allowed to fall back and strike a rapper bar, which is connected to a bank of collecting electrodes within the precipitator. The shock transmitted to the collecting electrodes dislodges the accumulated dust.

The electrical controls provide a number of separate adjustments, so that rappers can be assembled into a number of different groups and each group independently adjusted according to transmissometer readings. The controls are adjusted manually to provide adequate release of dust from collecting plates while preventing undesirable stack puffing.

In some applications the magnetic impulse, gravity impact rapper is also used to clean the precipitator discharge wires. In this case the blow is imparted to the electrode supporting frame in the same manner, except that an insulator isolates the rapper from the high voltage of the electrode supporting frame.

Vibrators

The purpose of a vibrating system is to create vibrations in either the collecting plates or the discharge wires in order to dislodge accumulations of particles so that the plates or wires are kept in optimum operating condition.

The vibrator is an electromagnetic device; of which the coil is energized by alternating current. Each time the coil is energized, the vibration set up is transmitted through a rod to the high-tension wire supporting frame and/or collecting plates. The number of vibrators depends on the number of high-tension frames and/or collecting plates in the system.

The control unit contains all devices for operation of the vibrators, including means of adjusting the intensity of vibration and the length of the vibration period. Alternating current is supplied to the discharge wire vibrators through a multiple cam-type timer to provide the sequencing and time cycle for energization of the vibrators.

For each installation, a certain intensity and length of vibration time will produce the best collecting efficiency. Insufficient intensity of vibration will result in heavy buildup of dust on the discharge wires, which can cause the following adverse operating conditions:

A reduction of the spark-over distance between the electrodes, which limits the power input to the precipitator.

A tendency to suppress formation of negative corona and the production of unipolar ions required for the precipitator process.

An alteration of the normal distribution of electrostatic forces in the treatment zone. Unbalanced electrostatic fields can cause the discharge wires and the high-tension frame to oscillate.

Upper Precipitator

On positive or negative pressure installations, a pressurizing fan is supplied (located on the cold roof) to force air into the top housing and down through the support bushings. This air prevents the process gases in the precipitator from entering the top housing and contaminating the support and high-tension frame rafter (vibrator) insulators. Electric heaters are also used.

In place of a top housing, some installations have insulator compartments. The insulator compartment is a steel enclosure that surrounds the high-tension frame support insulators and rapper rod insulators. Fans are provided to prevent condensation of moisture on the high-voltage support insulator, and sometimes electric heaters are installed near each bushing in each insulator compartment.

The purpose of the high-tension anvil beam, which is part of the high-tension frame, is to transfer the impact of the high-tension vibrator to the discharge wires.

Discharge Wires

The discharge electrodes are small-diameter wires suspended from a structural steel wire supporting frame, held taut by individual cast iron weights at the lower end and stabilized by a steadying frame at the top of the cast iron weights. Unshrouded and shrouded discharge wires are illustrated in Figures C-1-4 and C-1-5, respectively.

Collecting Plates

The gas flows horizontally in the precipitator through individual gas ducts formed by the collecting plates. The discharge wires are located midway between the plates for the purpose of ionizing the gases and imparting an electric charge to the dust particles. It is important that the

plate and wire spacing be held to close tolerances. Figure C-1-6 illustrates the type of collection plate used in many electrostatic precipitators manufactured by Research-Cottrell.

Lower Precipitator

The lower steadying frame limits or restricts the horizontal movement of the discharge wires.



Figure C-1-4. Discharge electrode unshrouded.

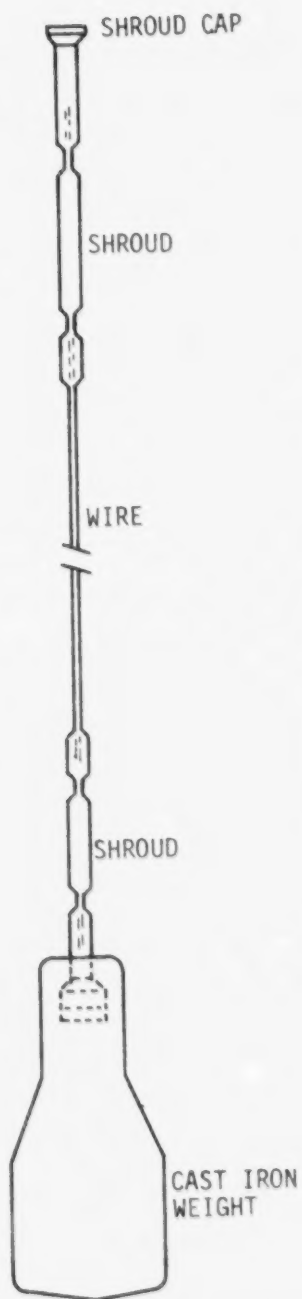


Figure C-1-5. Discharge electrode shrouded.

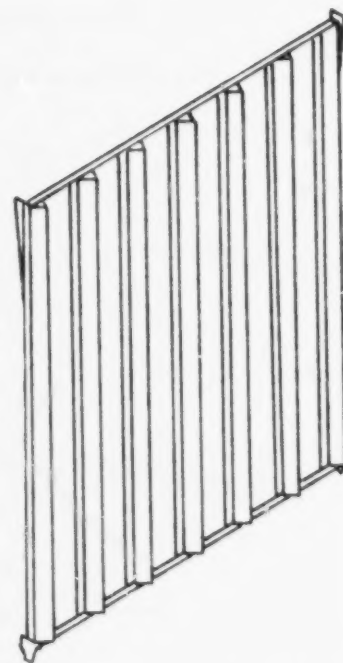


Figure C-1-6. Precipitating collecting electrodes.

APPENDIX C-2. PREOPERATING CHECKLIST FOR PRECIPITATORS

1.) General

Before start-up of the precipitator(s) and auxiliary equipment, a complete check and visual inspection of the following items should be performed.

2.) Precipitator

	Check	Initial	Date	Recheck	Remarks
a) Duct spacing					
b) Collecting plates					
° Bowing					
° Bellying					
° Supports					
° Spacer bars					
° Corner guides					
c) Gas sneakage baffles					
d) Anti-swing devices					
e) Hoppers					
° Dust level indicators					
° Outlet connections					
° Access doors					
° Poke holes - anvils					
° Vibrators					
f) Insulator housing					
° Support bushings					
° Access doors					
° Ventilation system					
° Bushing connections					
° Bushing heaters					

	Check	Initial	Data	Recheck	Remarks
o) Gaskets for high temperature					
3.) <u>Auxiliary Equipment</u>					
a) Transformer-rectifier units					
° Surge arrestor gap					
° Transformer liquid level					
° Ground connections					
°° Precipitator					
°° Transformer					
°° Rectifier					
°° H.T. bus duct					
°° Conduits					
°° FW/HW switch box					
°° Alram connections					
°° Contact making thermometer					
° Ground switch operation					
° High-voltage connections					
° Telephone jacks					
° Sound power jacks					
° Resistor board					
° Space heaters					
b) Rectifier control units					
° Controls grounded					
° Connections to equipment					
° Space heaters					
° Internal light and switch					
° Alarm connections					
° Space heaters					
c) Rapper control unit					
° Connections					
° Lights					
° Space heaters					
d) Vibrator control unit					
° Connections					
° Lights					
° Space heaters					

	Check	Initial	Data	Recheck	Remarks
e) F.D. Ventilation controls					
° Motor					
° Starters					
° Pushbutton stations					
° Alarm connections					
° Filters					
f) Electric heater controls					
° Hoppers					
° Insulator housing/ compartment					
° Roof enclosure					
° Control house					
g) Control house					
° Heaters					
° Ventilation					
° Motor control centers					
° Distribution panelboards					
° Lighting panelboards					
° Starters					
h) Screw conveyors					
i) Rotary feeder valves					
j) Zero speed detectors					
k) Speed reducers					
l) Trough type hoppers					
m) Inner doors - drag bottom level					
n) Air vibrators-Navco 3 in.					
o) Air vibrator controls					
p) Water spray piping					
q) Pillow block assembly					

- r) Automatic back draft
pampers
- s) Filter boxes - filters
- t) Butterfly dampers

Check	Initial	Date	Recheck	Remarks

APPENDIX C-3
ESP INSPECTION, MAINTENANCE, AND
TROUBLESHOOTING PROCEDURES

Transformer-Rectifier Sets and Associated Equipment and Controls

Check the liquid level in the transformer weekly. If it is low, fill the tank to the level indicated on the gauge with the dielectric liquid specified on the nameplate.

Dielectric fluid should be handled with extreme caution.

Clean high-tension insulators, bushings, and terminals during each outage to minimize surface leakage. Glazed porcelain is best cleaned with a damp cloth and a non-abrasive cleaner.

Once each year or more often, clean the contacts of relays and dress them with a fine grade crocus cloth.

Check the dustop filter weekly. The air filter assembly, easily attached and convenient for servicing, is mounted on the control cabinet.

Transformer Enclosure

Inspect all bushings and insulators. Replace those that are damaged; clean those that are dusty with a nonabrasive cleaner.

Clean all interlocks and lubricate with powdered graphite to ensure smooth and proper action.

Lubricate all bearing points on the ground-operated lever, connecting rods, and bevel gears.

Check all electrical connections to ensure that they are corrosion-free and tight. Loose electrical connections can cause electrical erosion of connections and failure of metering circuits and electrical components in both the control cabinet and transformer.

Overhead HW-FW Switchgear

Inspect all insulators for cracks, chips, and/or dust buildup. Replace all damaged insulators and remove dust accumulations with a nonabrasive cleaner.

Inspect all visible contacts to be sure that they are free of corrosion and pitting due to electrical arcing. Handcleaning, filing, and/or wire-wheel cleaning may be required.

Inspect for a tight fit on all couplings associated with transformer output bushings and switching insulators.

Lubricate mechanical bearing surfaces under the switching insulators to ensure smooth and proper operation.

Pipe and Guard

Remove all internal rust and/or scaling. Rust appearing on the internal walls of the guard could peel off and fall against the pipe, causing a ground on the secondary of the transformer.

Check the condition of the wall and post insulators for signs of electrical tracking (arcing), dust buildup, and cracked insulators. Clean or replace parts as required.

Check the pipe to ensure that all connections to wall bushings and post insulators are tight and that the pipe elbows used to redirect the pipe at various turns in the guard are tight and secure.

Ensure against water leakage by checking and maintaining the seal on the inspection plates of the pipe and guard.

When replacing the inspection covers, be certain to reinstall the ground jumper between the guard and cover plate; this ensures that any static charge or high-voltage leak goes to ground.

Plate Rappers

Check the rappers periodically for any possible binding of the plunger or misalignment of assembly. The maximum amount of energy can be transmitted from coil to plunger only when the plunger is properly located with respect to the coil. Any deviation will decrease the energy transmitted. Adjusting bolts allow changes of the distance between the lower casing and the mounting and thereby allows variation of the plunger insertion in the coil.

If boot seal or service sheet gasket has deteriorated, dismantle the rapper assembly and inspect the rapper rod sleeve for ash accumulation. Packed ash in this area will dampen shock wave to the collecting plate and cause excessive ash accumulation on the plates (wires). [A boot seal is the rubber seal that is stretch-fitted over the end of the rapper rod. On negative-pressure installations, the boot seal prevents air and water from entering the precipitator chamber through the rapper rod guide sleeve. On positive-pressure installations, the boot seal prevents precipitator gases from flowing up the rapper and guide sleeve and entering the rapper coil tube.]

Inspect striking end of plunger to insure that the end has not been flared or otherwise deformed due to excessive height in its lift and/or misalignment.

When reassembling the rapper assembly after maintenance has been performed, make certain that the coil and coil cover are plumb and level, and that the plunger is properly aligned in a vertical plane on the rapper rod.

The maintenance checks outlined above apply also to wire rappers.

Vibrators

Inspect each vibrator for proper gas setting.

Inspect boot seal for holes or tears and replace if necessary.

Inspect the service sheet gasket between the guide plate and the mounting nipple for signs of deterioration and replace if necessary.

If boot seal or service sheet gasket has deteriorated, dismantle the rapper rod assembly and inspect the vibrator rod nipple for ash accumulation. Packed ash in this area will dampen the vibrations to the discharge wires and cause excessive ash accumulation, close electrical clearances, and reduced precipitator performance.

Check for dust or signs of inleakage of air and/or water where the rapper rod passes through the packing ring retainer plate. This condition is indicative of a loose retainer plate providing an inadequate seal between the packing and the rapper rod, or of failure of the packing rings. A loose retainer plate should be tightened and in case of gas leakage, the packing should be replaced.

Upper Precipitator

Top Housing

Inspect the fan to ensure that it is working and that the filters are in good condition.

Inspect vent elbows for accumulation of foreign matter, which would reduce or cut off the air flow.

Check access doors, inspecting the gaskets for signs of deterioration and leaks. Replace defective gaskets and lubricate door lugs and hinges as required.

Check that interlocks are clean, and lubricate with powdered graphite.

Inspect the upper rapper (or vibrator) rod on the high-tension frame to ensure that it is centered in its guide nipple and that no dust has packed between the nipple and the rapper/vibrator rod. If the rapper/vibrator rod needs to be centered in the nipple, cover the insulator with an asbestos blanket, and with a torch cut the nipple loose from the cold roof. Reposition the nipple, centering the rod, and reweld the nipple to the cold roof. Care must be taken that the

new weld is a complete seal; water and ambient air could flow through pinholes and contaminate the insulators.

Note: Whenever it is necessary to do any welding on the high-tension wire supporting frame, the electrical bus connection to the high-tension support bushing should be disconnected. A heavy, temporary ground, sufficient to carry total welding current, should be solidly connected to the high-tension frame. The disconnected bus should be securely grounded at both ends; i.e., in the rectifier ground switch enclosure and at the support bushing end.

Insulator Compartments

Energize high-tension frame vibrators and check for smooth operation. Check field wiring and vibrator control cabinet if an inoperative vibrator is found. Vibrator insulator nuts and all pipe plugs should be secure.

Check all nipples and seals.

Inspect all dampers in the duct connections to the compartments to ensure that they are in the open position. Operate pressurizing fan and check that air is flowing uniformly into each insulator compartment.

The vent elbow should be equipped with a pipe plug unless the installation is operating under negative pressure, in which case there should be no plug. Inspect the elbow for dust and/or other foreign material.

Inspect the pipe and guard through the inspection hatch to ensure that the inside surface is free from dust accumulation and/or rust and scale. Remove all dust accumulations and/or rust and scale buildups to prevent high-voltage arcing from the pipe to the guard. Inspect insulators to ensure that they are free from cracks, chips, and dust accumulations. Replace any cracked or chipped insulators and clean dirty insulators with a nonabrasive cleaner.

Inspect the gasket on the inspection door for deterioration and leaks; replace worn or leaky gaskets. Make sure that all bolts are in place and securely fastened. Determine that interlock is operable and well-lubricated with powdered graphite.

Inspect upper rapper rod (see Section 3.1.3.3).

Inspect the rapper rod insulator for dust accumulations, chips, cracks, and electrical tracking. Electrical tracking that has not damaged the glazed surface of the insulator and dust accumulations should be cleaned off with a nonabrasive cleaner. Replace cracked, chipped, or glaze-damaged insulators.

Inspect the area between the rapper rod and the hanger pipe for packed dust accumulations. Remove any accumulation, since it tends to dampen the vibration transmitted to the upper high-tension frame. Check to see that the rapper rod is centered in the support pipe. If the support pipe is off center, chances are that the weld between the lower rapper rod and the upper high-tension frame was broken. Recenter the rod and reweld it to the high-tension frame. As with the upper rapper rod, inspect the insulator clamp, ensuring that all bolts are in place and tight.

Check the high-tension frame support pipe. Inspect the round nut screwed onto the support pipe to prevent pipe movement.

Remove the cover plates and inspect the inside and outside surfaces of the support insulator for dust accumulations, electrical tracking, cracks, and chips. Dust accumulations and electrical tracking that have not damaged the glazed surface of the insulator should be cleaned with a nonabrasive cleaner.

Plate Hanger Anvil Beam

Inspect the anvil beam hanger rod clips to ensure that they are straight. Excessively heavy plate rapping can in time cause these clips to bend, causing the plate bank to shift out of alignment. This shift results in electrical clearances out of tolerance and reduced precipitator performance.

Inspect the hanger rods themselves to ensure that none are broken, missing, or bent.

Inspect the area behind the plate hanger anvil beam for packed dust. Remove dust, since it can force the beam out of plumb.

Inspect the weld between the rapper rod and the anvil beam. If this weld is broken or cracked, it should be replaced.

Upper High-Tension Frame

Check bolts and welds on the high-tension frame.

Replace broken, bent, or missing support rods.

Check wire support angles for broken welds where they attach to the spacer beam. Repair broken welds, making sure that the wire support angles are parallel and on 9-in. centers (assuming 9-in. plate-to-plate spacing).

Check to determine whether the high-tension frame is level both perpendicular and parallel to the gas flow. If the frame is not level in the direction of gas flow, adjust at the appropriate high-tension frame support rods. If the frame is not level perpendicular to the gas flow, adjust at the appropriate high-tension frame hanger pipes.

Check for excessive accumulation of dust on this frame. Accumulations are excessive if they interfere with specified clearances of 4-1/2 in. + 1/4 in. between the discharge wires and collecting plates, or if they create a clearance of less than 4-1/2 in. between the high-tension frame and any other grounded surface (assuming 9-in. plate-to-plate spacing).

Discharge Wires

Whenever possible, determine the condition of the discharge wires with regard to dust buildup. The amount of buildup will indicate whether the high-tension vibrators, when furnished, are operating at the proper intensity.

The discharge wires should be kept as clean as is practical.

Inadequate rapping of the discharge wires can result in heavy dust buildup, with localization of the corona current and excessive sparking.

A deposit on the discharge wires results from many things, including poor gas distribution and charac-

teristics of the dust. Doughnut-shaped deposits often are formed. They are composed generally of finer dust particles. Deposits on the discharge wires do not necessarily result in poor performance, although depending on resistivity, power supply range, and uniformity of the deposit they can reduce efficiency.

The discharge wires should be perfectly centered between the plates from top to bottom for optimum precipitator operation. Any broken discharge wires should be removed and if time permits, replaced with new wires. Since a cast iron weight is connected to each wire at its lower end, a resistance will be felt when pulling on the wire. A wire that gives no resistance is broken.

Broken wires can sometimes be seen from catwalks located between the collecting plate banks. With a flashlight, look down each duct noting any bottle weight that is hanging on its bottle guide and any wires that are out of alignment.

The location of a broken wire that is removed but not replaced should be recorded on a permanent log sheet. This recording will save time during future outages when time permits the installation of a new wire. A record of broken wire locations is also helpful in determining the cause of wire breakage, i.e., if a number of wires break in the same area of the precipitator, there are alignment problems. If the wire breakage is random, the breakage is probably caused by dust buildups on wires or plates.

The damaged wire may be cut away and the replacement wire brought into the precipitator through the top upper high-tension frame area, placed in the proper duct, lowered into place, and attached.

Collecting Plates

Whenever the precipitator is out of service and internal inspections are possible, the collecting plates should be checked for proper alignment and spacing. Check all hangers. Make sure that spacers at the bottom of the plates do not bind plates to prevent proper rapping. Check the lower portion of all plates and the portion of plates adjacent to any door openings for signs of corrosion. If corrosion is present, it usually indicates air inleakage through hoppers or around doors.

Observe the dust deposits on the collecting plates before starting any cleaning of the precipitator. The normal thickness of collecting dust is about 1/8 in. with occasional buildups of 1/4 in. If the buildup exceeds this amount, the intensity of the plate rappers should be increased. If the collecting plates are almost metal clean, this may be an indication of high gas velocity, extremely coarse dust, too high a rapping intensity, or too low an operating voltage for good precipitation. This condition may be noted if a section has been shorted-out prior to the inspection.

The plate may be in effect removed from service by removing the discharge wires surrounding it. When bellying or bowing of the plates is noted, the concave side of the plate may be heat-treated with a torch, depending upon the severity of the deformity.

Lower Precipitator Steadying Frame

Cast iron weight rings that are bent out of their normal configuration must be straightened. This can usually be done by hand.

Inspect the steadying bars for cracked or broken welds where they mount to the steadying bar support. Perform any needed repairs.

Make sure that the lower steadying frame is level both in the direction of gas flow and perpendicular to gas flow. If the frame is not level, readjust the support wires, adjusting both until the frame is level. Place equal tension on each of the support wires connected to adjusting bolts, since slack wires will cause excessive sparking.

Inspect the steadying frame for downward bow in the steadying bars (usually occurs after operating the precipitator at overdesign temperatures). Downward bows can usually be removed by cutting a wedge-shape slot in the vertical member of the steadying bar angle, pushing with jacks or pulling with a block-and-tackle until the frame is straight, then welding an additional piece of angle iron inside the steadying bar angle and across the wedge slot.

Inspect the steadying frame for twisting. A twisted frame causes excessive weight on some wires and slackness in others. To straighten a twisted frame, grasp one end of the frame and twist the frame until that end is straight and level. While holding the frame in this position, weld the frame to the hopper walls. Repeat for the other end of the frame. Once the frame has been welded to the hopper walls and is straight and level, using a torch, stress-relieve the frame by heating each connection between the steadying bar supports and the steadying bars until it glows to a cherry red. After all joints have been relieved, allow the frame to cool, then cut it free of the hopper walls. If the frame is still twisted, repeat the procedure. If after the second heating the frame is still twisted, a new frame will have to be installed.

When checking the lower steadying frame anti-sway insulators, check the surface for dust accumulation, glaze damage caused by electrical tracking, cracks, and chips. Insulators with dust accumulation and/or electrical tracking that have not damaged the glazed surfaces may be cleaned with a nonabrasive cleaner. Cracked, chipped, broken, or glazed-damaged insulators must be replaced.

Hoppers

Hoppers are often of the trough type with screw conveyors. If properly sized, screw conveyors offer reliable operation and continuous removal of collected dust. Pyramidal hoppers are also installed using rotary and double-dump valves. Given these systems, hoppers are not generally used as "storage bins" for collected dust as is often the case with fly ash utility installations. To prevent corrosion, heaters can be used to prevent the formation of corrosive condensables. Any abnormal buildups should be removed. If this condition becomes chronic, it is an indication of low operating temperatures, insufficient heat insulation, or inadequate hopper emptying. Heat tracing of the hoppers will usually correct this condition unless it is due to inadequate hopper emptying.

Precipitator Shell

Sulfur trioxide, chlorine, and moisture can promote serious corrosion. The traces of sulfur trioxide result in fairly rapid corrosion of the interior of gas ducts, fans, and dust-collecting equipment if these interior surfaces become cool for any reason. It is therefore recommended that thorough internal inspection be made during the first year of operation. If interior corrosion is noted, apply some means of correction as soon as possible. Heat insulation applied to exteriors of the corroded components will normally correct this condition. Since iron and steel process operations can fluctuate widely, covering interior surfaces of side frames, end frames, and roof with Gunitite will prevent damage to the steel.

Maintenance Schedule and Troubleshooting

Annual Inspection/Maintenance

Prior to any inspection, it is of utmost importance that the precipitator is deenergized and grounded and that the necessary precautions are taken to ensure that the equipment cannot be energized during the internal inspection.

Dust Accumulations

Observe the dust accumulations on both plates and wires. The discharge wires should have only a slight coating of dust with no corona tufts (doughnut-shaped dust accumulations). Thickness of dust buildup on plates is normally between 1/8 and 1/4 in. If the plates have more than 1/4 in. of dust, the rappers are not cleaning properly.

Discharge Wires

Replace any broken discharge wires, necked-down wires, or fatigued wires to avoid the possibility of breaking during operation. Breakage of just one wire may render an entire precipitator section inoperative. Record the exact location of all wire failures as well as the location of breakage on the wire.

Alignment of Plates and Wires

The plate-to-wire clearances at both top and bottom of plates should not be less than 4-1/4 in., while the minimum acceptable plate-to-wire clearance at the vertical midpoint of the plates is 4 in. (assuming 9-in. duct spacing). Close electrical clearances create excessive sparking and prevent optimum operation.

High-Tension and Plate Rappers

Check all high-tension and plate rappers for misalignment and/or binding of the rapper rods through roof sleeves. Binding in this area prevents transmission of rapper energy to the collecting plates and high-tension discharge wires and results in excessive dust accumulations.

High-Tension Frame Support Bushing

The internal and external surfaces of the high-tension frame support bushing must be maintained free of dust to guard against high-voltage electrode tracking across insulator surfaces. This condition will lead to thermal fracturing of the bushings through heat concentration. Clean all high-voltage insulators and check thoroughly for sign of cracks; replace where necessary. All electrical connections should be secure.

High-Voltage Electrical Control Cabinet

Clean all components of dust accumulation and lubricate where necessary. Replace the ventilating fan filter.

Transformer-Rectifier Sets

Check the oil level in the high-voltage transformer and add the proper oil if necessary. Check all bushings, terminals, and insulators for dust buildup and evidence of electrical tracking. Check the surge arrester gap setting on the high-voltage transformer and readjust if necessary. Check high-voltage switchgear and interlocks.

Hoppers

Check for dust buildup in upper corners of hoppers and debris such as fallen wires and weights in the hopper bottom and valves. Inspect antistatic insulators to see that they are clean and not cracked. If a discharge electrode weight has dropped 3 inches, this indicates a broken wire.

Precipitator Shell

Interior corrosion could indicate inleakage of air or moisture through the housing. Exterior inspection should focus on loose insulation and joints, air leakage, and general damage as well as corrosion.

Daily Inspection and Readings

Record all control set electrical readings once per shift. Any abnormalities in shift-to-shift readings may well be the first clue of a malfunction within the precipitator. In addition, the daily log should include process operating data, flue gas analysis, dust analysis, verification of transmissometer calibration, and a record of all transmissometer readings.

Rappers

Ensure that all collecting plate and discharge wire (high-tension) rappers are functioning properly and operating at the proper intensity level. Lack of rapping will result in dust buildup on both the plates and wires, which reduces electrical clearances and necessitates operation of the equipment at reduced power levels. Over-rapping of the internals leads to reentrainment of collected dust; therefore, it is important that proper intensity values be used for optimum precipitator performance.

Hoppers

Thoroughly check all hoppers, particularly the unloading mechanism and system, for proper operation. Check thoroughly for air inleakage at the hoppers. The siphoning of cold ambient air into the hoppers usually results in formation of condensation and agglomerating of dust, resulting in plugging of the hopper.

A troubleshooting chart for ESP's is presented in Table C-3-1.

Frequency of failure of various precipitator components and repair times for a typical industrial precipitator are presented in Table C-3-2.

Table C-3-1. TROUBLESHOOTING CHART FOR ELECTROSTATIC PRECIPITATORS

Symptom	Probable cause	Remedy
Spark meter reads high, primary voltage and current very unstable	Misadjustment of automatic control, loss of limiting control	Readjust automatic control, replace automatic control
Neither spark rate, current, nor voltage at maximum	Misadjustment of automatic control, automatic control not at maximum, failure of signal circuits	Readjust setting of automatic control, check signal circuits
No spark rate indication, voltmeter and ammeter unstable, indicating drifting	Failure of spark meter, failure of interlocking solenoid, spark meter set too low	Replace spark meter, replace capacitor, readjust potentiometer on automatic control
No response to current-limit adjustment, response to other adjustments	Controlling on spark rate or voltage limit, failure of automatic control, current signal to automatic control defective	None needed if unit is operating at maximum spark rate or voltage adjustment, reset voltage or spark rate if neither is at maximum, replace automatic control, check signal circuit
No response to voltage-limit adjustment, response to current adjustment	Controlling on current limit or spark rate, voltage signal to automatic control defective, failure of automatic control	None needed if unit is operating at maximum current or spark rate, reset current and spark rate adjustment if neither is at maximum, check voltage circuit, replace automatic control
No response to spark rate adjustment, response to other adjustment	Controlling on voltage or current, failure of automatic control	None needed if unit is operating at maximum voltage or current, reset voltage and current adjustment if neither is at maximum, replace automatic control
Precipitator current low with respect to primary current, low or no voltage across ground return regulator	Large section shorted, H.V. rectifiers failed, H.V. transformer failed, ground or partial ground in the ground return circuit	Inspect or replace surge diodes, replace H.V. rectifiers, replace H.V. transformer, repair ground return circuit

(continued)

Table C-3-1. (Continued)

Symptom	Probable cause	Remedy
	Transformer-Rectifier Controls	
No primary voltage, no primary current, no precipitator current, vent fan on, alarm energized	D.C. overload, misadjustment of current limit control, overdrive of SCR's	Check overload relay setting, check wiring and components, check adjustment of current-limit control setting, check signal from firing circuit module
No primary voltage, no primary current, no precipitator current, vent fan off, alarm energized	Control panel fuse blown, loss of power supply, circuit breaker tripped	Replace fuse or reset circuit breaker, check supply to control unit, reset circuit breaker
Control unit trips out on overcurrent when sparking occurs at high currents	Overload circuit incorrectly set	Reset overload circuit
High primary current, no precipitator current	Short circuit in primary current, transformer or rectifier short	Check primary power wiring, check transformer and rectifiers
No primary voltage, no primary current, no precipitator current, vent fan on, alarm not energized	SCR and/or diode failure, no firing circuit	Replace, check signal from firing circuit
Low primary voltage, high secondary current	Short circuit in secondary circuit or precipitator	Check wiring and components in H.V. circuit and pipe and guard. Check precipitator for interior dust buildup, full hoppers, broken wires, ground switch left on, ground jumper left on, foreign materials on H.V. frames or wires, broken insulators
Abnormally low precipitator current and primary voltage with no sparking	Misadjustment of current and/or voltage limit controls, misadjustment of firing circuit control	Check settings of current and voltage limit controls
Spark meter reads high-off scale, low primary voltage and current, no spark rate indication	Continuous conduction of spark counting circuit, spark counter counting 60 cycles peak, failure of automatic control	Deenergize, allow integrating capacitor to discharge and reenergize, adjust spark control circuit, replace automatic control

(continued)

Table C-3-1. (Continued)

Symptom	Probable cause	Remedy
Primary current and secondary current normal, primary voltmeter drops from normal to zero and remains for a second then jumps back to normal, repeating this sequence rhythmically	Broken wire, swinging frame	Remove broken wire, check for broken anti-sway bushings
Circuit breaker trips	Rapper Controls	Check wiring and component
Fuses blown, indicator light not flashing	Short circuit or component failure in control circuit or power transformer	Replace defective component, replace coil, repair or realign distributor switch
Indicator light not flashing, no fuse failure	Control circuit failure, rapper coil failure, distributor switch firing two coils at once	Repair or replace component, check motor and drive train
No manual intensity control	Control circuit not operating effectively, no rotation of distributor switch	Replace potentiometer, replace intensity control module
Vibrator inoperative	Failed potentiometer, faulty intensity control module	
Abnormal ammeter reading	Vibrators and Controls	
Line breaker trips	Vibrator coil open circuited, vibrator improperly adjusted	Replace coil, adjust vibrator
	Vibrator improperly adjusted, vibrator coil short circuited	Adjust vibrator, replace coil
	Short circuit in control wiring	Check circuit

Table C-3-2. FREQUENCY OF FAILURE AND REPAIR TIMES REQUIRED
FOR VARIOUS PRECIPITATOR COMPONENTS. ^a

	Electrical repair - external -				Mechanical/electrical repair - internal -					
	Rectifier controls	Transformer	Rapper coil	Pressure fans	Collecting electrodes	Discharge electrodes	Top and bottom high tension frames	Support bushings	Lower high tension stabilizer bars	Rapper shafts
Frequency of failure	Seldom	Seldom	Seldom	Seldom	No failure	5-7 yr ^a	No failure ^b	5-10 yr	Seldom	No failures
Time to repair	1-6 h	1 day	1 h	2 h	1 wk (one section)	1 h		2 h	1 h	
Parts	Stocked	Stocked	Stocked	Not stocked	Not stocked	Not stocked	Not stocked	Stocked	Stocked	Stocked
Complete units	12 wk	12 wk	Stocked	6-8 wk	4-6 wk	1 wk	2 wk			

^a Average life; replace with collecting electrodes.

^b Possibly replace with collecting electrodes.

REFERENCES - APPENDIX C-3

1. "Industrial Air Pollution Guide," PEDCo Environmental, Inc., Chapter 7.0, (draft report) EPA contract No. 69-01-4147.

APPENDIX C-4.

PROCEDURES FOR TROUBLESHOOTING AND CORRECTION OF

BAGHOUSE MALFUNCTIONS¹

(RP-reverse pulse; PR-plenum pulse; S-shaker; RF-reverse flow)

Symptom	Cause	Remedy
High baghouse pressure drop	Baghouse under-sized	Consult manufacturers. Install double bags. Add more compartments or modules.
	Bag cleaning mechanism not adjusted properly	Increase cleaning frequency. Clean for longer duration. Clean more vigorously.
	Compressed air pressure too low (RP, PP)	Increase pressure. Decrease duration and/or frequency. Check dryer and clean if necessary. Check for obstruction in piping.
	Repressuring pressure too low (RF)	Speed up repressuring fan. Check for leaks. Check damper valve seals.
	Shaking not strong enough (S)	Increase shaker speed.
	Isolation damper valves not closing (S, RF, PP)	Check linkage. Check seals. Check air supply on pneumatic operators.
	Bag tension too loose (S)	Tighten bags.
	Pulsing valves failed (RP)	Check diaphragm. Check pilot valves.

APPENDIX C-4 (continued)

PROCEDURES FOR TROUBLESHOOTING AND
CORRECTION OF BAGHOUSE MALFUNCTIONS

Symptom	Cause	Remedy
Low fan motor amperage/low air volume	Cleaning timer failure	Check to see if timer is indexing to all contacts. Check output on all terminals.
	Not capable of removing dust from bags	Condensation on bags (see below). Send sample of dust to manufacturer. Send bag to lab for analysis for blinding. Dry clean or replace bags. Reduce air flow.
	Excessive re- entrainment of dust	Continuously empty hopper. Clean rows of bags randomly, instead of sequentially (PP, RP).
	Incorrect pres- sure reading	Clean out pressure taps. Check hoses for leaks. Check for proper fluid in manometer. Check diaphragm in gage.
	High baghouse	See above.
	Fan and motor sheaves reverse	Check drawings and reverse sheaves.
	Ducts plugged with dust	Clean out ducts and check duct velocities.
	Fan damper closed	Open damper and lock in position.

APPENDIX C-4 (continued)

PROCEDURES FOR TROUBLESHOOTING AND
CORRECTION OF BAGHOUSE MALFUNCTIONS

<u>Symptom</u>	<u>Cause</u>	<u>Remedy</u>
Dust escaping at source	System static pressure too high	Measure static on both sides of fan and review with design. Duct velocity too high. Duct design not proper.
	Fan not operating per design	Check fan inlet configuration and be sure flow is even.
	Belts slipping	Check tension and adjust.
	Low air volume	See above.
	Ducts leaking	Patch leaks so air does not bypass source.
	Improper duct balancing	Adjust blast gates in branch ducts.
Dirty discharge at stack	Improper hood design	Close open areas around dust source. Check for cross drafts that overcome suction. Check for dust being thrown away from hood by belt, etc.
	Bags leaking	Replace bags. Tie off bags and replace at later date. Isolate leaking compartment if allowable without upsetting system.
	Bag clamps not sealing	Check and tighten clamps. Smooth out cloth under clamp and re-clamp.

APPENDIX C-4 (continued)

PROCEDURES FOR TROUBLESHOOTING AND CORRECTION OF BAGHOUSE MALFUNCTIONS

Symptom	Cause	Remedy
Excessive fan wear	Failure of seals in joints at clean/dirty air connection	Caulk or weld seams.
	Insufficient filter cake	Allow more dust to build up on bags by cleaning less frequently. Use a precoating of dust on bags (S, RF).
	Bags too porous	Send bags in for permeability test and review with manufacturer.
	Fan handling too much dust	See above
	Improper fan	Check with fan manufacturer to see if fan is correct for application.
Excessive fan vibration	Fan speed too high	Check with manufacturer.
	Buildup of dust on blades	Clean off and check to see if fan is handling too much dust (see above). Do not allow any water in fan (check cap, look for condensation, etc.).
	Wrong fan wheel for application	Check with manufacturer.

APPENDIX C-4 (continued)

PROCEDURES FOR TROUBLESHOOTING AND
CORRECTION OF BAGHOUSE MALFUNCTIONS

<u>Symptom</u>	<u>Cause</u>	<u>Remedy</u>
High compressed air consumption	Sheaves not balanced	Have sheaves dynamically balanced.
	Bearings worn	Replace bearings.
	Cleaning cycle too frequent	Reduce cleaning cycle if possible.
	Pulse too long	Reduce duration (after initial shock all other compressed air is wasted).
	Pressure too high	Reduce supply pressure if possible.
Reduced com- pressed air pressure (RP, PP)	Damper valves not sealing (PP)	Check linkage. Check seals.
	Diaphragm valve failure	Check diaphragms and springs. Check pilot valve.
	Compressed air consumption too high	See above.
	Restrictions in piping	Check piping.
	Dryer plugged	Replace dessicant or bypass dryer if allowed.
Premature bag failure - decomposition	Supply line too small	Consult design.
	Compressor worn	Replace rings.
	Bag material im- proper for chemi- cal composition of gas or dust	Analyze gas and dust and check with manu- facturer. Treat with neutralizer before baghouse.

APPENDIX C-4 (continued)

PROCEDURES FOR TROUBLESHOOTING AND
CORRECTION OF BAGHOUSE MALFUNCTIONS

<u>Symptom</u>	<u>Cause</u>	<u>Remedy</u>
Moisture in baghouse	Operating below acid dew point	Increase gas temperature. Bypass at start-up.
	Insufficient pre-heating	Run system with hot air only before starting process gas flow.
	System not purged after shut-down	Keep fan running for 5-10 minutes after process is shut down.
	Wall temperature below dew point	Raise gas temperature. Insulate unit. Lower dew point by keeping moisture out of system.
	Cold spots through insulation	Eliminate direct metal line through insulation.
	Compressed air introducing water (RP, PP)	Check automatic drains. Install aftercooler. Install dryer.
	Repressuring air causing condensation (RF, PP)	Preheat repressuring air. Use process gas as source of repressuring air.
High screw conveyor wear	Screw conveyor undersized	Measure hourly collection of dust and consult manufacturer.
	Conveyor speed too high	Reduce speed.
High air lock wear	Air lock undersized	Measure hourly collection of dust and consult manufacturer.

APPENDIX C-4 (continued)

PROCEDURES FOR TROUBLESHOOTING AND
CORRECTION OF BAGHOUSE MALFUNCTIONS

<u>Symptom</u>	<u>Cause</u>	<u>Remedy</u>
Material bridging in hopper	Thermal expansion	Consult manufacturer to see if design allows for thermal expansion.
	Speed too high	Reduce speed.
	Moisture in bag- house	See above
	Dust being stored in hopper	Remove dust con- tinuously.
	Hopper slope in- sufficient	Rework or replace hoppers.
Frequent screw conveyor/air lock failure	Conveyor opening too small	Use a wide flared trough.
	Equipment under- sized	Consult manufacturer.
	Screw conveyor misaligned	Align conveyor.
High pneumatic conveyor wear	Overloading com- ponents	Check sizing to see that each component is capable of handling a 100% delivery from screw conveyor.
	Pneumatic blower too fast	Reduce blower speed.
	Piping under- sized	Review design and reduce speed of blower or in- crease pipe size.
Pneumatic con- veyor pipes plugging	Elbows too short radius	Replace with long radius elbows.
	Overloading pneu- matic conveyor	Review design.

APPENDIX D-1

PREDICTED PERFORMANCE OF VENTURI
SCRUBBERS ON SELECTED IRON AND STEEL
PROCESSES USING RESEARCH COTTRELL'S MODEL

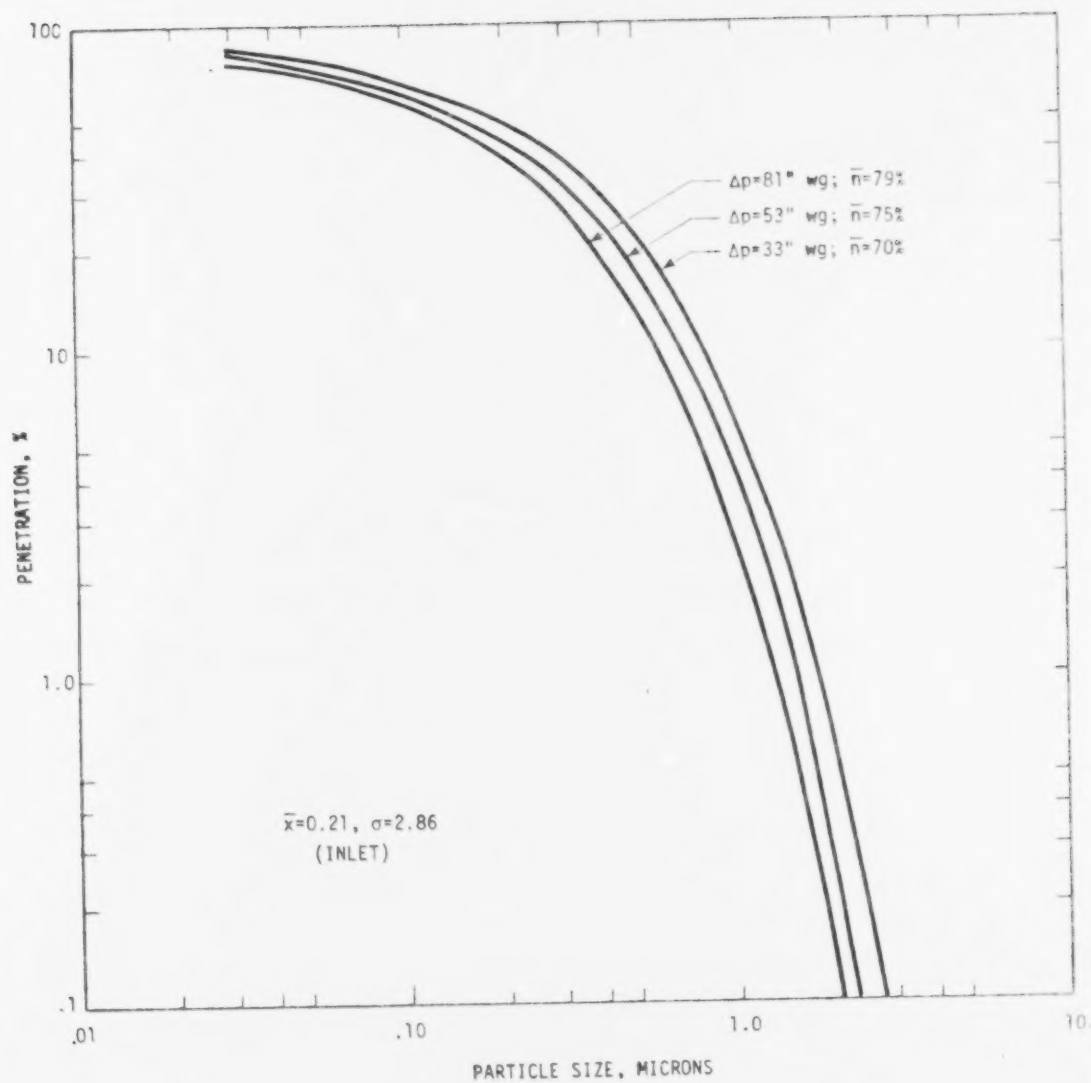


Figure D-1-1. Venturi scrubber penetration for open hearth furnace; L/G - 15

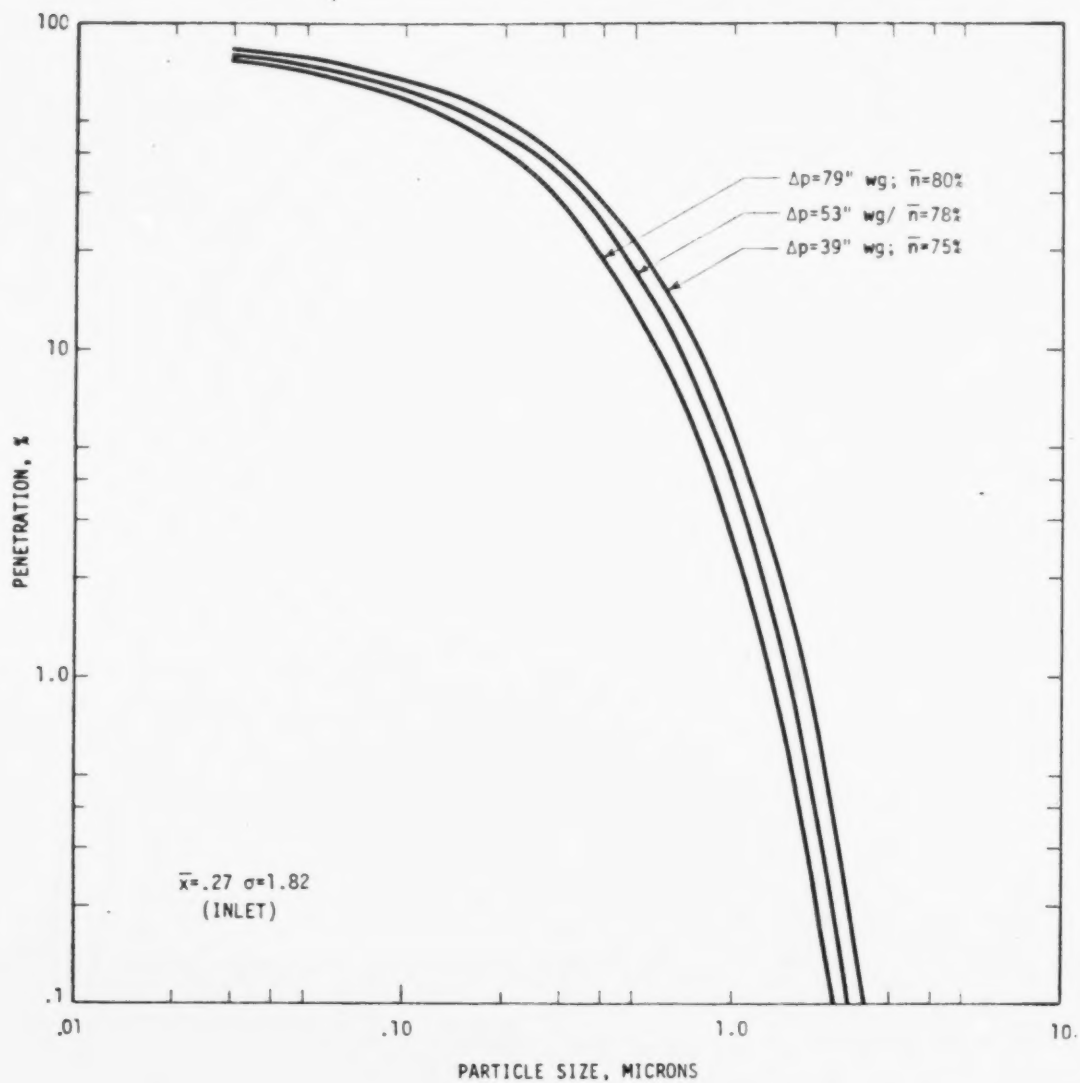


Figure D-1-2. Venturi scrubber penetration for open hearth furnace; $L/G = 15$

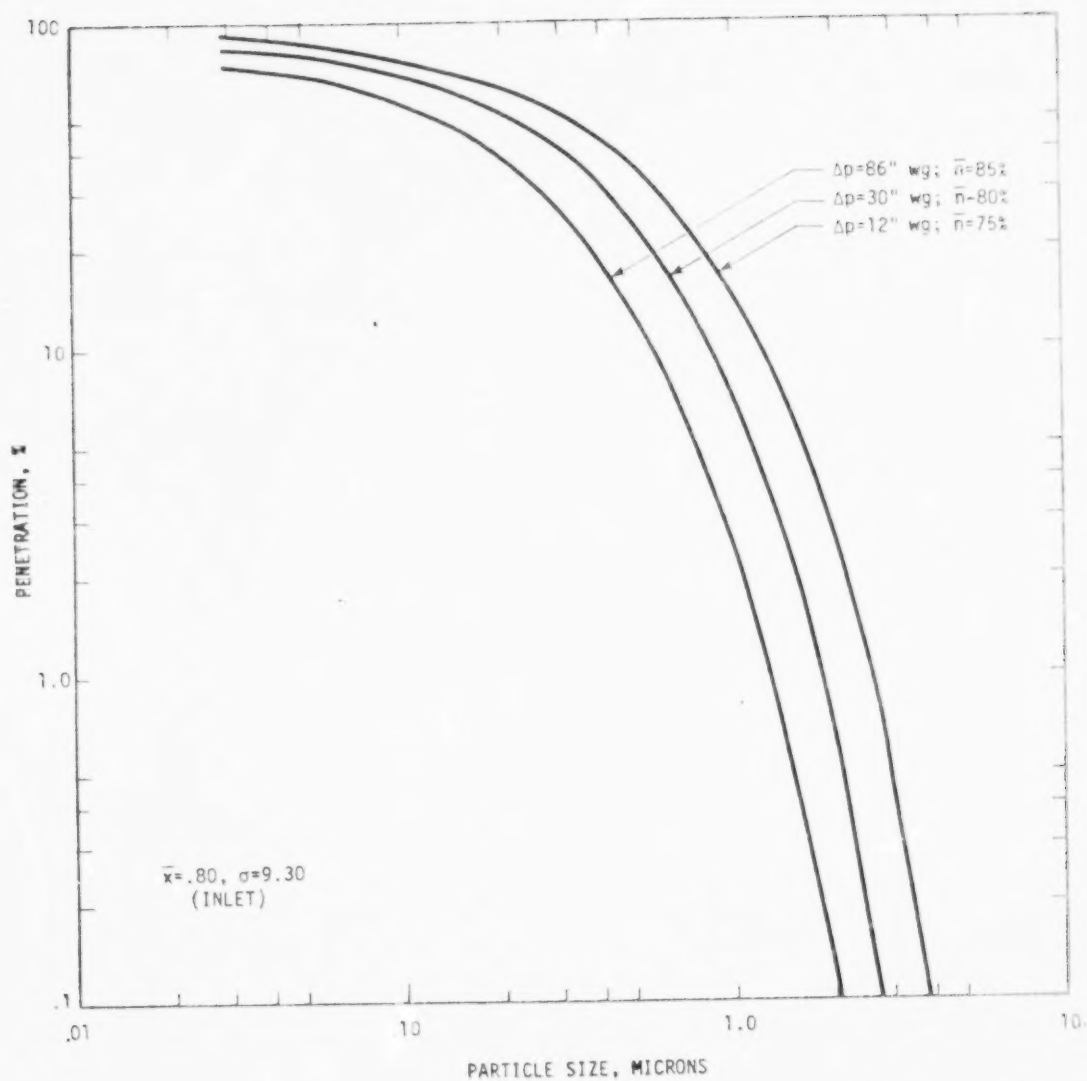


Figure D-1-3. Venturi scrubber penetration for electric arc furnace; L/G - 15

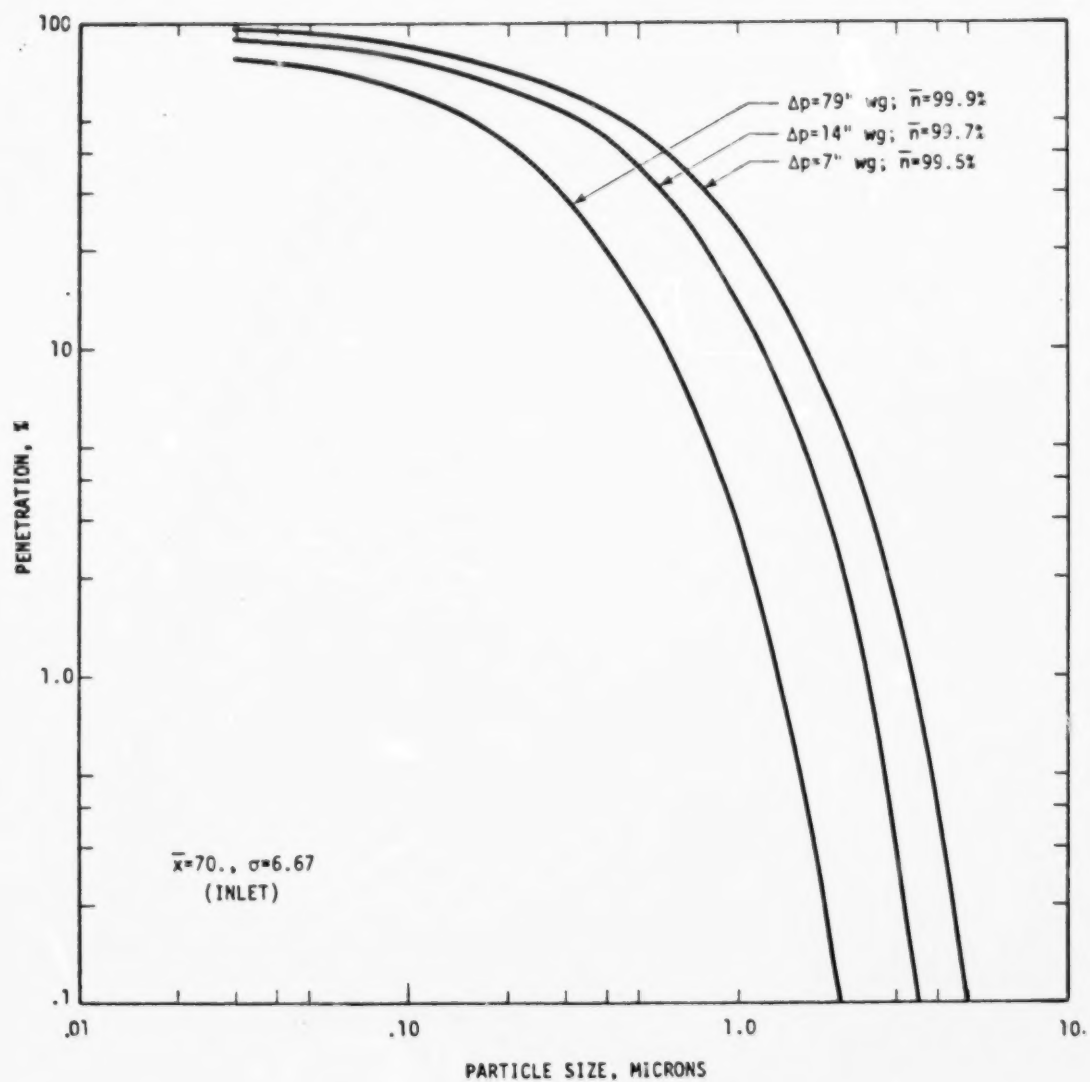


Figure D-1-4. Venturi scrubber penetration for sintering machine; $L/G = 15$

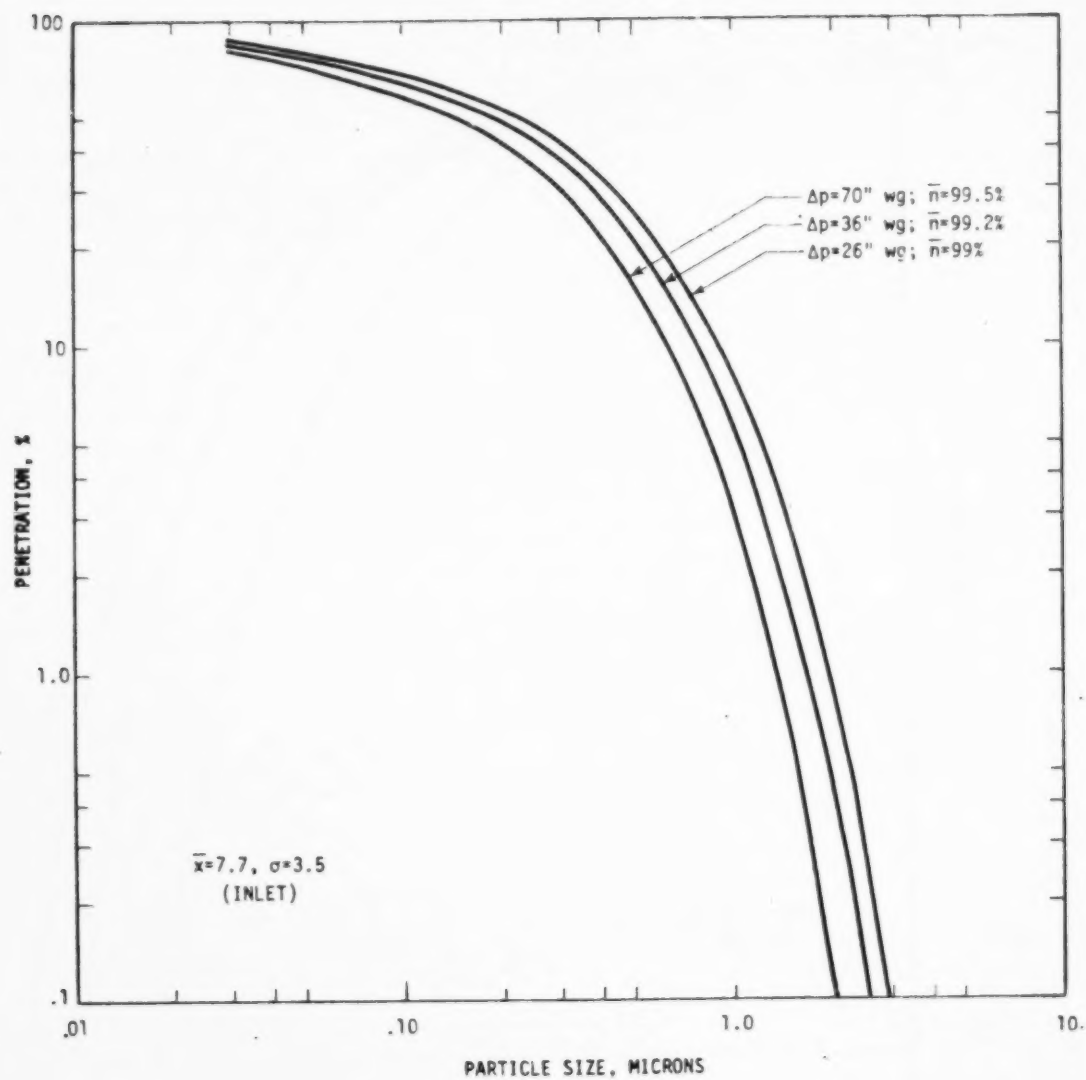


Figure D-1-5. Venturi scrubber penetration for sintering machine; $L/G = 15$
(scrubber preceded by mechanical collector)

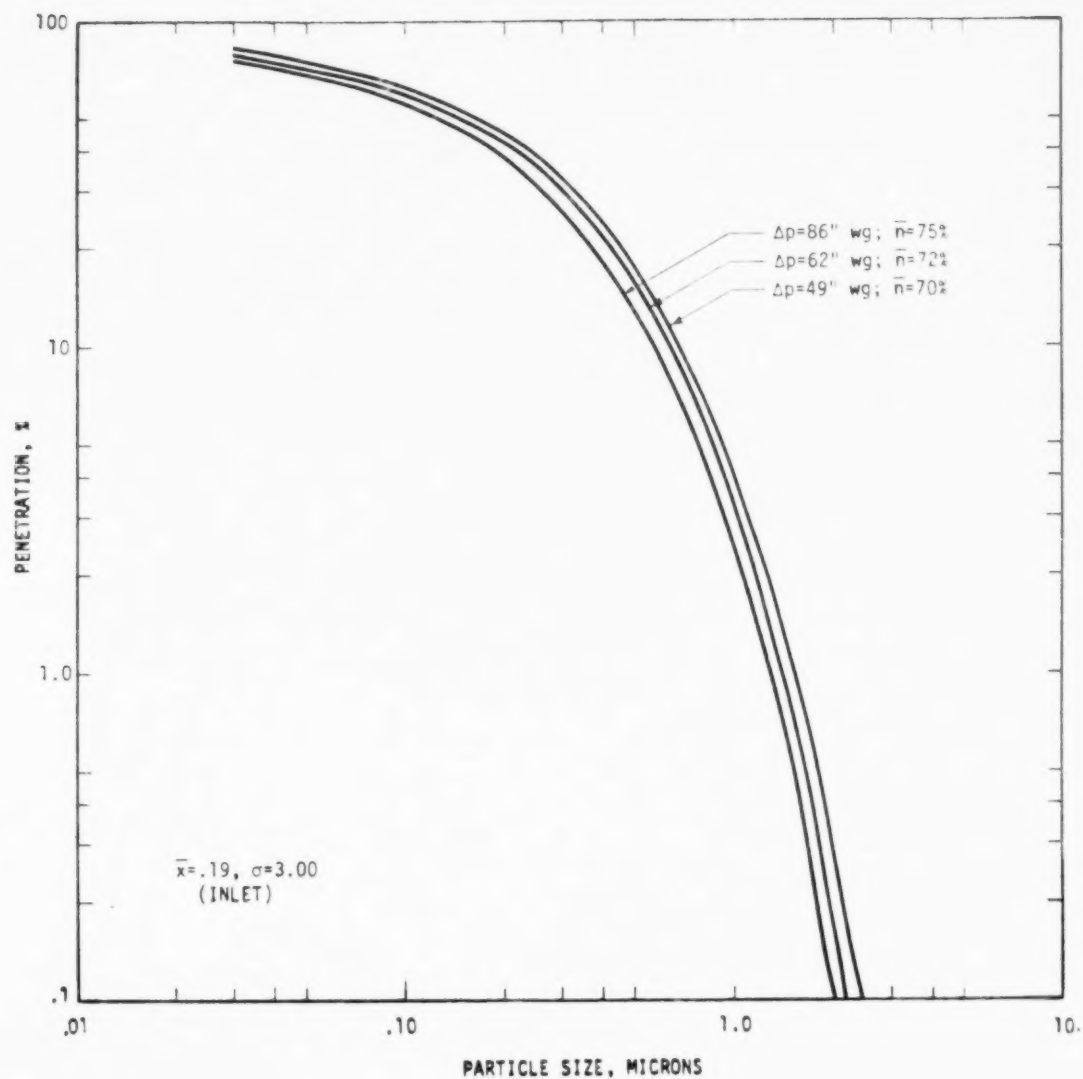


Figure D-1-6. Venturi scrubber penetration for ferrosilicon arc furnace; $L/G = 15$

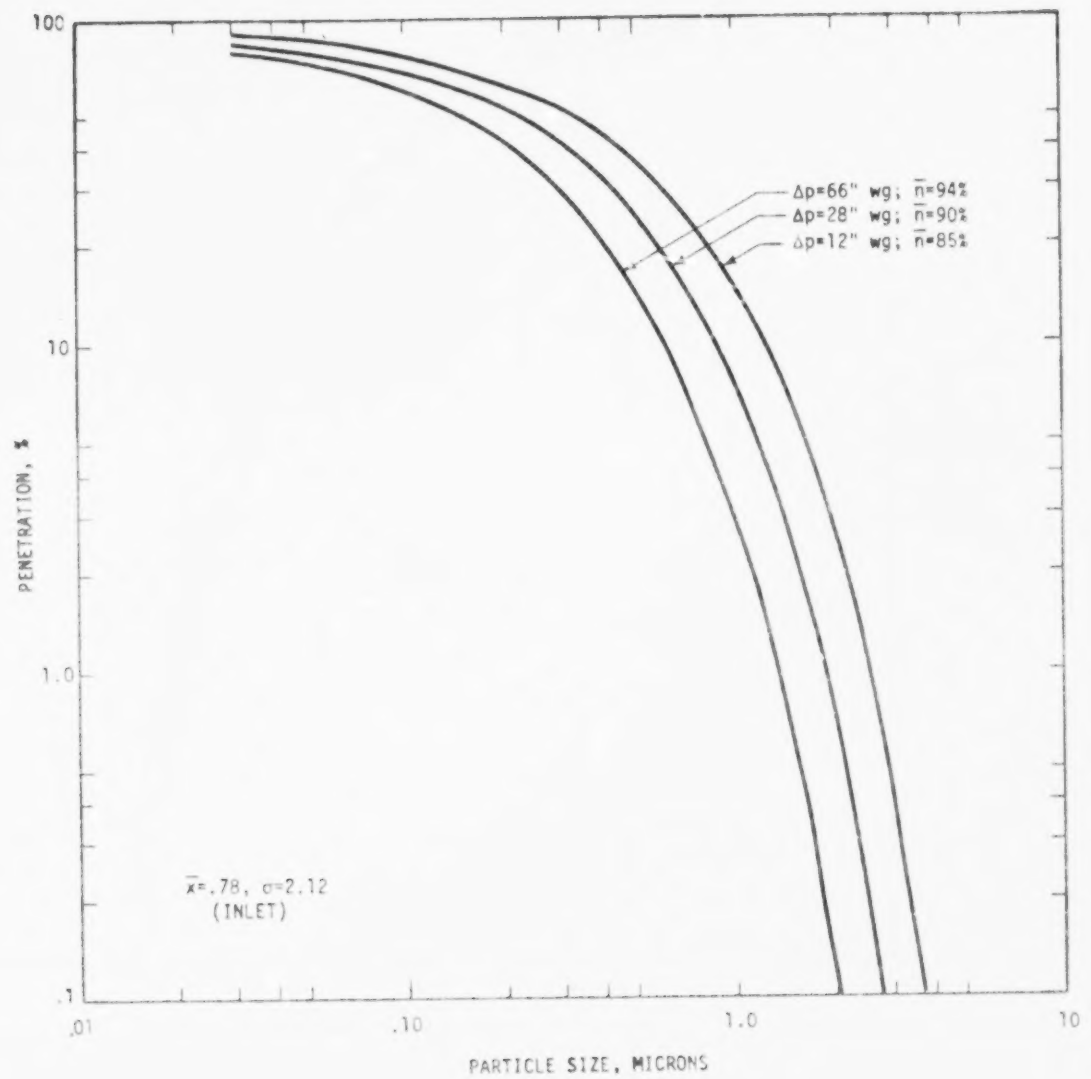


Figure D-1-7. Venturi scrubber penetration for ferro-manganese arc furnace; $L/G = 15$

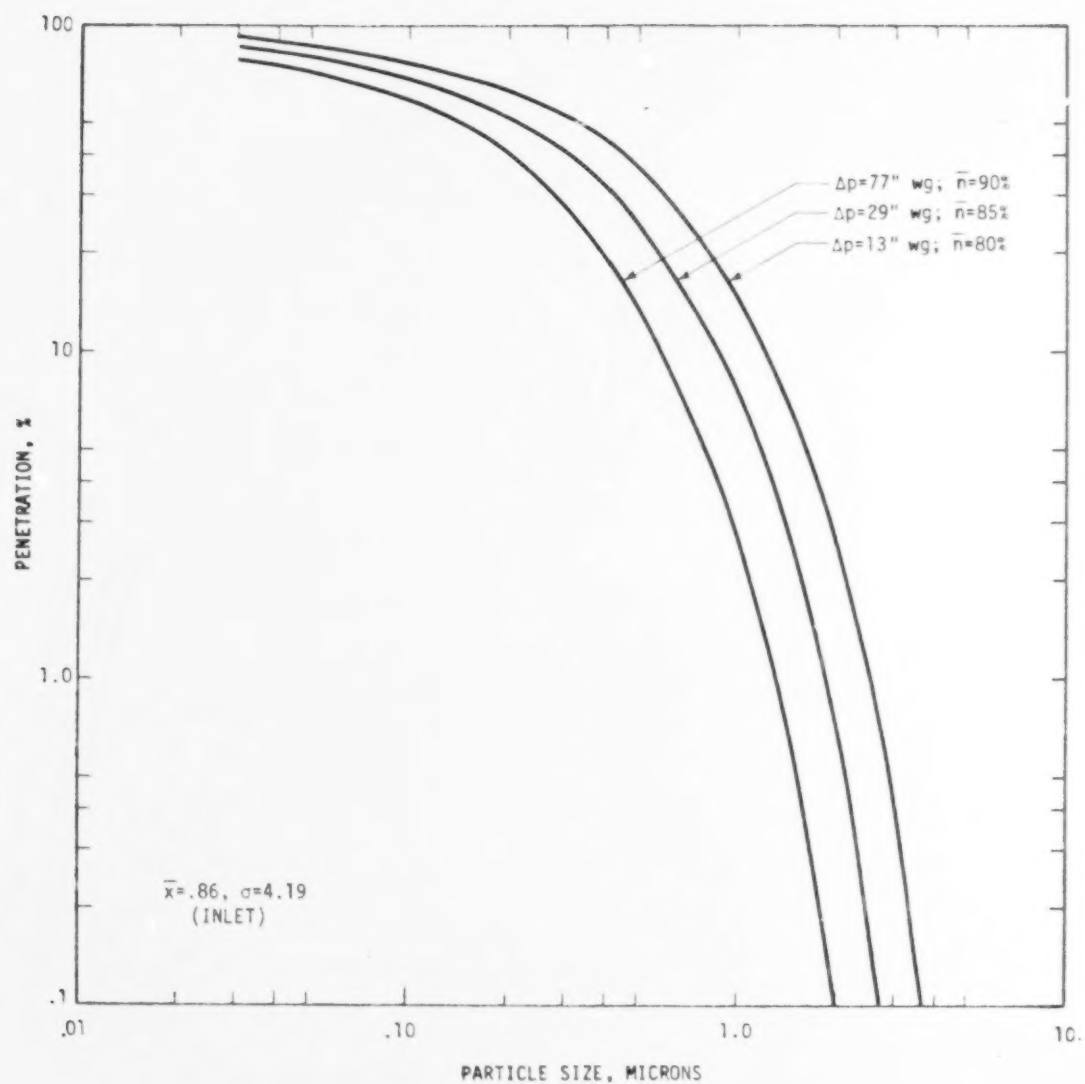


Figure D-1-8. Venturi scrubber penetration for ferro-chromium arc furnace; L/G - 15

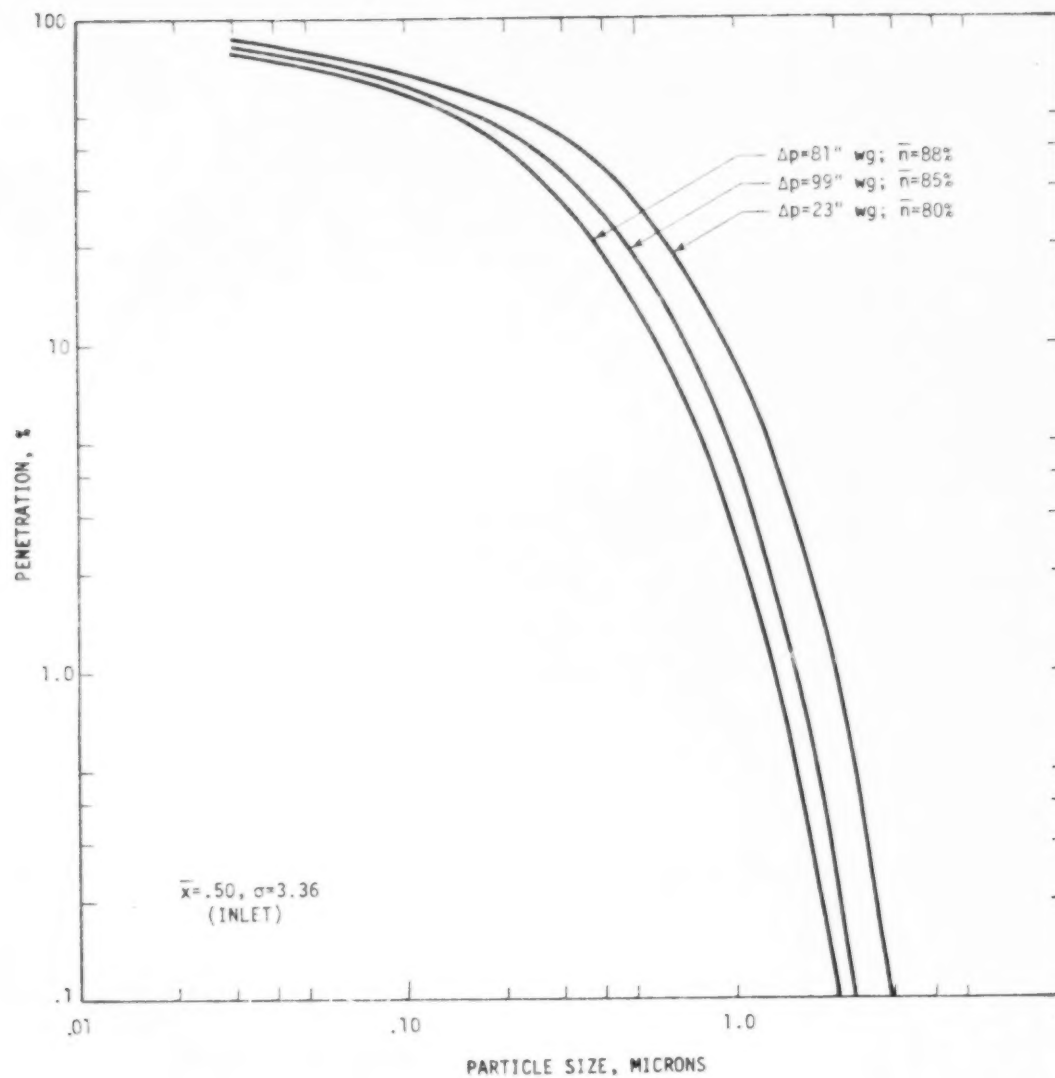


Figure D-1-9. Venturi scrubber penetration for miscellaneous ferroalloy arc furnace; L/G - 15